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STUDY OF AEROSPACE STRUCTURAL MANUFACTURING CONCEPTS

VOLUME 2 OF 3

MANUFACTURING LINE MODEL DESCRIPTIONS, ANALYSES, AND RESULTS

15 MARCH 1971

PREPARED FOR:

National Aeronautics and Space Administration
Office of Advanced Research and Technology
Contract NAS2-5857

BY

APOLLO SYSTEMS • SPACE DIVISION
GENERAL ELECTRIC COMPANY
DAYTONA BEACH, FLORIDA

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FOREWORD

This report presents the results of a Study of Technology Requirements for Structures of Aerospace Vehicles. This study was performed for the National Aeronautics and Space Administration under Contract NAS2-5857, monitored by Mr. Kenji Nishioka and Mr. Harry Hornby of the Advanced Concepts and Missions Division of the Office of Advanced Research and Technology.

We wish to acknowledge the many organizations and individuals who provided us with data pertinent to this study. A list of these organizations and individuals is included at the end of Volume 3.

SUMMARY

This report describes the activities of a three phase study of the economics of aerospace structural manufacturing. The study is devoted primarily to the examination of the technology areas pertinent to conventional (aluminum) aerospace manufacturing. Two representative structures are used in a systems analysis of the impact of technology and program factors on manufacturing. The initial manufacturing lines are defined using today's state-of-the-art procedures and costs. Facilities, tooling, premanufacturing operations, materials, manufacturing and quality control labor are indicated. Improvements in overall operations and manufacturing technology are introduced to define improved and advanced manufacturing lines.

A computer model was developed for accumulating and manipulating manufacturing data and costs and is described in detail. This program, together with those factors and technologies identified with improved manufacturing processes, has been used to assess the impact on cost and worth.

The five major areas of investigation and primary sources of data in these areas are summarized in Table 1. Information related to the manufacturing technologies has been derived primarily from Government and industry sources typified by Saturn/Apollo structural manufacturing experience.

Results for representative structures indicate that the recurring part of the manufacturing processes cost is not the major portion of the total manufacturing cost. In general it has been shown that for the manufacture of a propellant tank the facilities, tooling and other nonrecurring costs represent from one-half to three-fourths of the total manufacturing cost. This result, therefore, isolates an area which should receive further attention in future studies for significant cost saving potential.

No single factor has a more significant impact on cost than the quantity of like elements produced. For example, with a production capability of 20 elements per year, the manufacturing cost of each element when producing 100 is less than 7 percent of the cost of producing one element. This result reflects the effect of spreading the nonrecurring costs over a larger base.

Table 1

Sources of Manufacturing Data

Area of Investigation	Primary Sources of Data for This Study
Pre-Manufacturing Technologies	MSFC, Grumman, North American Rockwell, McDonnell Douglas Astronautics Co., GE/RESD, GE/AS
Manufacturing Technologies • Metal Removal • Metal Forming • Assembly & Other	MSFC, Air Force Manufacturing Lab, Battelle, Grumman, North American Rockwell; GE/RESD, GE/AS, GE/Jet Engine, GE/Manufacturing Services; McDonnell Douglas Astronautics Co., plus 26 Subcontractors
Quality Control & Test Technologies	MSFC, GE/RESD, GE/AS, North American Rockwell, McDonnell Douglas Astronautics Co., Grumman
Factors Affecting Manufacturing	MSFC, GE/RESD, GE/AS, Grumman, North American Rockwell, Air Force Manufacturing Lab, Univ. of Florida (Dr. Burns), Batelle, GE/Manufacturing Services, McDonnel Douglas Astronautics Co.
Plant Facilities	MSFC, GE/RESD, GE/AS, Grumman, North American Rockwell, GE/Manufacturing Services, McDonnell Douglas Astronautics Co., Grumman

MANUFACTURING ACRONYMS/ABBREVIATIONS

Acronym/Abbreviation	Description
+	And
A/A	Assembly Area
A/D	Aft Dome
A/F	Assembly Facility
ASSY	Assembly
BLK	Blank
C/B	Common Bulkhead
C/C	Center Cap
CHEM	Chemical
CK	Check
CLN	Clean
CYL	Cylinder
DYE-PEN	Dye-Penetrant
EXTER	External
F/D	Forward Dome
FWD	Forward
INSP	Inspection
INSTL	Install
INTER	Internal
L/T	LOX Tank
LD	Load
LK	Leak
LOX	Liquid Oxygen
MTL	Material
OPNG	Opening
PKG	Package
REQ	Required
S/B	Spreader Bar
SEG	Segment
SHIP	Shipping
STA	Station
TRNSPR	Transporter
U/I	Ultrasonic Inspect
WGH	Weigh

SECTION 1

INTRODUCTION

1.1 BACKGROUND

Previous studies have shown that significant reductions in structural weight can be achieved with the use of advanced materials in future large launch vehicles. General Electric Company, under contract, NAS2-3811[7], has shown that structural weight reductions of 60 to 70 percent can be realized in large launch vehicles with the substitution of materials such as beryllium or boron/epoxy honeycomb for the conventional aluminum integrally stiffened skin construction. This weight reduction is significant in improving launch vehicle performance. Technological areas, proven to be of interest in the above study for future large launch vehicles, were evaluated parametrically by the General Electric Company, under contract NAS2-5047, for technical feasibility and economic characteristics[1].

This study is essentially a continuation of the above studies and is a broad investigation of the manufacturing technology of aluminum aerospace structural systems to identify the significant manufacturing factors influencing overall structural system manufacturing cost. Results from the study are necessary to provide a manufacturing system cost baseline and cost analysis tools and techniques along with the identification of potential areas for cost reduction. This baseline will serve as the foundation upon which to develop cost indices and reductions for future aerospace programs utilizing advanced materials and related manufacturing technologies.

Other studies presently in progress and/or completed for the NASA Office of Advanced Research and Technology complement this study. Boeing Aircraft performed a detailed cost study of large launch vehicles which provides a range of payload capability under contract NAS2-5056, "Cost Studies of Multipurpose Large Launch Vehicles." McDonnell-Douglas Aircraft Corporation developed a cost model and performed cost studies of spacecraft under contract NAS2-5022, "Study of Optimized Cost/Performance Design Methodology for Orbital Transportation Systems." North American-Rockwell has studied the costs of a spectrum of launch vehicles from performance and cost viewpoints under contract NAS7-368, "Influence of Structure and Material Research on Advanced Launch Systems' Weight, Performance and Cost."

The successful achievement of larger launch vehicles such as Saturn IB, Saturn V, and Titan III has not brought the expected reduction in costs of launch vehicles. Instead, these multi-billion dollar launch vehicle developments have produced launch vehicles of unprecedented success and reliability. The importance of achieving safe and successful flights has dominated the development cycle; launch vehicle costs remain at the $500 per pound to $1000 per pound level.

To achieve desired costs for vehicles, all systems of the launch vehicles should be designed on an optimized cost/performance basis. This study explored structural manufacturing since it represents a large portion of the launch vehicle costs and a wealth of background data could be assembled for evaluation.

Unlike other studies, this study's objective is to take a broader look at manufacturing costs—particularly from the context of a total program environment. Other earlier studies (e.g., References 9, 10) have covered particular constructions and the costs for various methods of fabrication. This study seeks to develop the comparative manufacturing costs of representative structures within the total framework of a typical space program. Where possible, impact of program-wide factors, such as safety, reliability, configuration control, program phasing, tolerance control, quality control, etc., have been considered. The enormity of this undertaking is evident from the size of such programs—as in the case of Apollo which cost billions of dollars and employed hundreds of thousands of workers. To achieve this goal, representative structures have been identified and their manufacturing lines described by using a computer model which makes it possible to consider the impact of advancements in technology and changing program factors. In this manner, the study team has been able to discern where potential future cost reductions may be available from a total program viewpoint.

The performance of this study has been assisted by numerous individuals from several departments within the General Electric Company. The following individuals were principal contributors to this study:

N. E. Munch	General Electric Apollo Systems
R. B. Bradshaw	General Electric Apollo Systems
Dr. E. Mangrum	General Electric Apollo Systems
E. W. Pittner	General Electric Re-Entry Systems

In addition, Dr. J. J. Burns of the University of Florida served as a consultant.

SECTION 2

STUDY APPROACH

2.1 INTRODUCTION

This study was divided into three phases spanning a nine-month period plus an additional three months for report preparation.

As illustrated in Figure 2-1, Phase I, was performed during a two-month period and consisted of three major elements: (1) acquisition of manufacturing data, (2) manufacturing technology status review, and (3) investigation of the interrelation of manufacturing parameters and system factors, such as program management, engineering, and design. In addition, supporting studies were performed in the areas of the specific disciplines related to manufacturing procedures, techniques, cost, and fabrication line modeling.

Phase II of this study was performed in four months and has included the detailed investigation of representative manufacturing baselines for two aerospace structures. After selection of two representative structures, manufacturing analyses were made to document the details of the tooling, facilities, and manufacturing for two production rates. Impact of manufacturing technologies were investigated through a detailed study of the impact of changing technologies and factors on these manufacturing lines. Changes in manufacturing line configuration, tooling, facilities, and processes were observed as the technologies, designs, and factors were varied. Descriptions of the lines obtained for each of the major steps of this evaluation are included in this report. Results of the economic analyses of the impact of these factors and technologies are given in later sections of this report.

A computerized mathematical model was developed to aid in this study and is in itself one of the significant products of this investigation. This model is programmed to describe the details of the basic manufacturing lines, as well as those lines which include potential recognized improvements. Program factors and constraints influencing manufacturing have been included to allow rapid calculation of the impact of these factors on manufacturing cost during Phase II of this study. While developed for specific representative structures, this type of computer program should have application in the future for analysis of impact of program factors and constraints on any manufacturing line. Descriptions of this program are included in Section 4 and Appendix A.

Phase III activities spanned a three-month period. During this period, the manufacturing lines and technology, defined in Phase II, were evaluated for cost and worth. Promising areas for future study were identified. Figure 2-1 depicts those work elements considered to accomplish this objective during Phase III. After establishing criteria for rating technology differences, a cost analysis was performed for all manufacturing lines, both manufacturing rates, and both structural elements. An interaction analysis was performed to determine the sensitivity of these costs to other system factors. The remainder of Phase III entailed the relative evaluation of these analyses and a final selection of technology areas worthy of future study.

The computer program developed and tested in Phase II was exercised, utilizing inputs representing variations in both manufacturing and other system factors. For each distinct set of input data which defines the structure to be manufactured and the constraints under which this process is to be completed, cost calculations were performed at the "element" level for all feasible identified manufacturing alternatives. The determination of the cost distribution including both recurring and nonrecurring cost associated with each of the three manufacturing lines for elements 1 and 2 was completed. The costs include all costs normally incurred during manufacturing and are in sufficient detail to permit meaningful cost comparisons between lines 1, 2 and 3.

Table 2-1 summarizes the approach and activities for the total study.

2.2 SCOPE

2.2.1 STRUCTURAL ELEMENTS SELECTED FOR DETAILED STUDY

At the conclusion of Phase I, the two separate structural elements shown in Figures 2-2 and 2-3, were selected for detail study in Phases II and III. These structural elements were selected because current manufacturing technologies and related cost could be established for the predetermined production rates of 2 and 20 per year for total programs up to five years in length.

The first structural element selected, Figure 2-2, was the Support Frustum, similar to the MARK XII frustum manufactured by the General Electric Company.

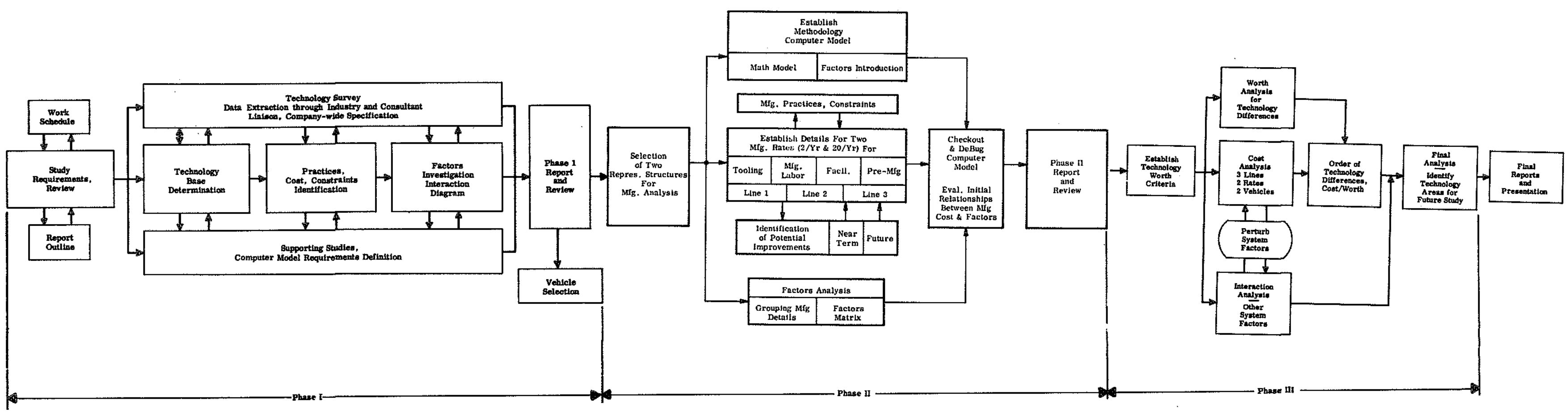


Figure 2-1. Work Flow Plan

Table 2-1

Summary of Study Activities

Phase I—Survey of Manufacturing Techniques and Factors

a. Selection of Areas to be Surveyed.
b. Survey of the Selected Areas.
c. Evaluation of Survey Data and Identification of Cost Impacting Factors.
d. Selection of Specific Structural Elements and Manufacturing Technologies for Phase II Study.

Phase II—Representative Manufacturing Lines and Model Description

a. Selection and Detailed Development of Manufacturing Computed Model.
b. Identification of Manufacturing Lines and Potential Areas for Improvement.
c. Identified Phase III Plans to Determine Sensitivity of Manufacturing Cost, to Changes in System Factors (Developed in Phase I), and To the Interaction of Two or More System Factors Concurrently Impacting the Manufacturers System.

Phase III—Manufacturers System Analyses

a. The Impact of Manufacturing Technology Differences and Changes in Factors Upon Manufacturers Cost.
b. Interaction Analyses of More than One Change in a Factor Concurrently Impacting the Manufacturing System Cost.

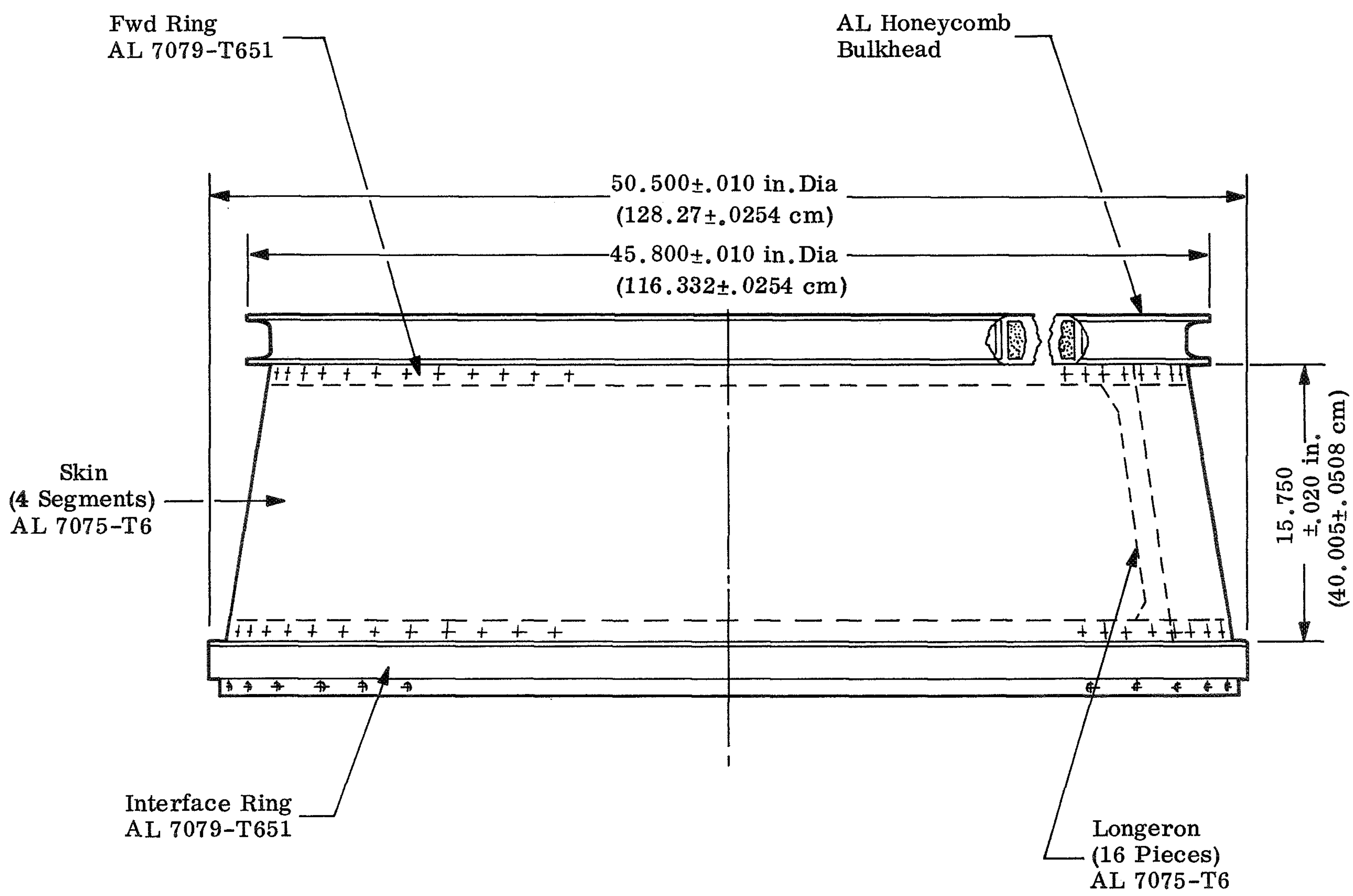


Figure 2-2. Support Frustum Structure (Structural Element No. 1)

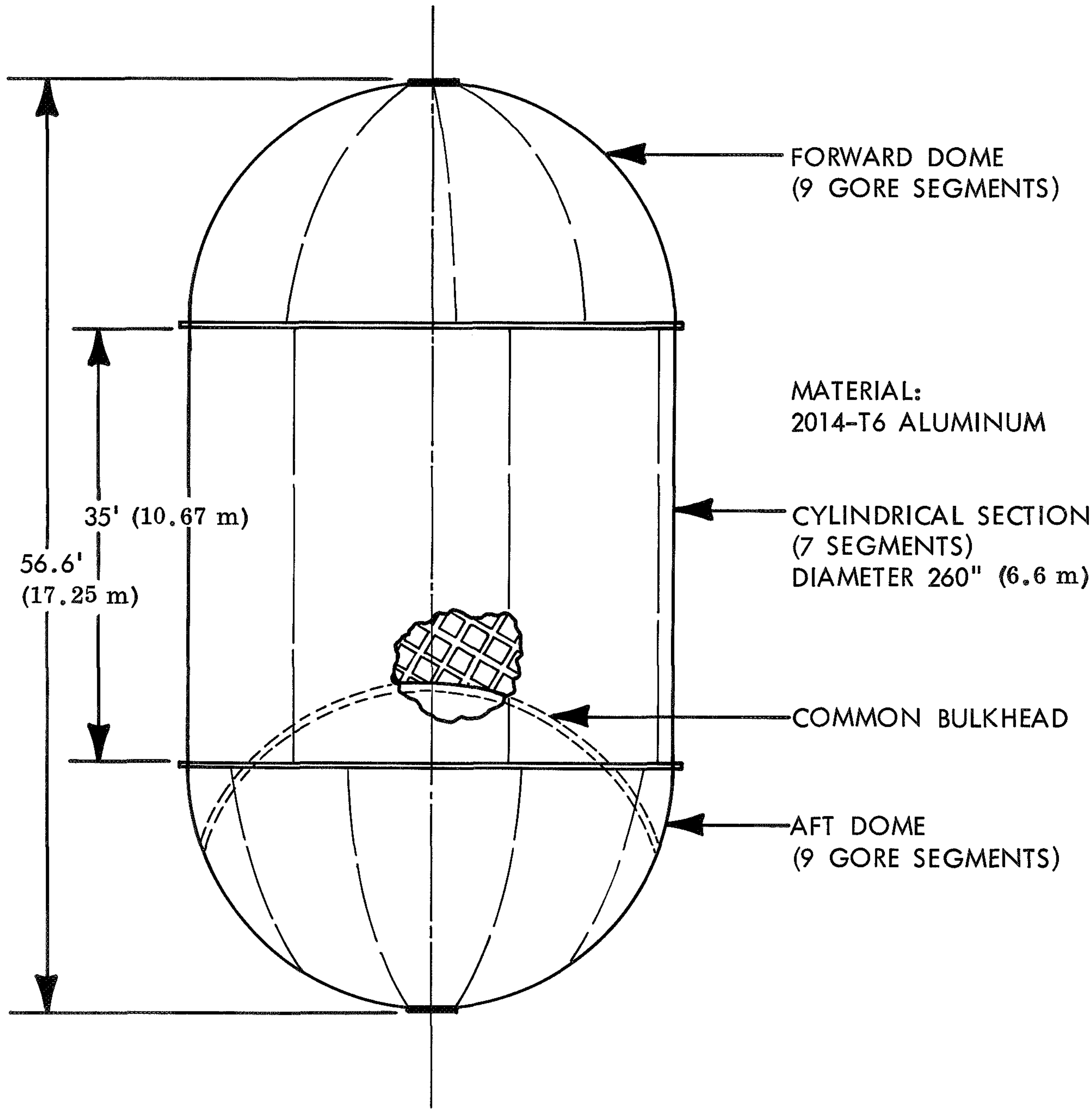


Figure 2-3. Propellant Tank Structure (Structural Element No. 2)

The second structural element selected, Figure 2-3, was a large propellant tank such as used in a Saturn V Launch Vehicle Stage. This tank is generic and design dimensions were established for a tank 21.6 feet in diameter and 56.6 feet long. A generic type of structure was selected rather than an actual structure to facilitate objectivity in the manufacturing analysis and to avoid undue reflection on a particular Apollo Saturn V component.

For each of the above structures, state-of-the-art manufacturing lines, including facilities, tooling, fabrication and assembly processes, labor requirements, and related costs were established for production rates of 2 and 20 per year. Actual data supplied by the General Electric Company, Space Division adjusted for the selected production rates was used in developing the state-of-the-art line for Structural Element No. 1. Facilities, tooling, fabrication, and assembly processes for the state-of-the-art line for Structural Element No. 2 are a composite of those used throughout the aerospace industry for such structures, as determined during the survey trips. Related cost data were developed by the General Electric Company cost estimating personnel based upon experience, discussions with tooling manufacturers, and appropriate related data.

Using the state-of-the-art line as a base and the computer model as a tool for analysis, problem areas were identified and solutions were developed and placed in the following three categories:

a. Solutions Readily Available.
b. Solutions Require Technology Development.
c. Solutions Require Major Technology Development.

Changes to the state-of-the-art lines brought about by the (a) solutions formed the base of the improved line, and changes to the improved line brought about by the (b) and (c) solutions were instrumental in forming the advanced line.

Through the application of the manufacturing model described in Section 4, studies were made of the effect on cost caused by changing various factors; i.e., quantity, quality, reduction in number of design changes, etc., for the manufacturing lines while considering various rates for facilities and tooling, depreciation, property tax, and interest on capital invested.

2.2.2 ASSUMPTIONS

In arriving at cost for facilities, tooling, material, labor, and processes, the assumptions shown in Table 2-2 were used.

These assumptions were developed from numerous contacts with vendors and industry. In particular, the Air Force Manufacturing Engineering Laboratory was helpful in establishing typical costs used in study calculations. Care should be exercised in use of the absolute values of cost derived in this study since cost values vary with time and geographic location.

Since this study is primarily focused on obtaining a baseline for current manufacturing technology, study attention was concentrated on the aluminum alloys that are the principal materials used in space vehicle structures. Future studies should be performed to evaluate the impact of advanced structural materials, such as beryllium and carbon filament composites, on future manufacturing costs.

2.2.3 STUDY VARIABLES

This study is broad in scope, and evaluates the impact of many different factors and technologies on program cost. A list of such variables is shown in Table 2-3. Variables include the types of structure, lines, quantity, costs, elements, learning curves, and numerous other factors. In many cases, these variables are correlated and interaction effects are studied.

The number of cases if all these interactions were studied would be the product of the number of observations in Table 2-3, a number approaching one million. To keep the study within manageable bounds, the 12 basic combinations of 2 structures, 2 rates, and 3 lines were considered as a baseline for study evaluation. This continued to preserve the broad scope of the study. Other variables have been considered for several of these basic manufacturing lines. The results have been interpreted to identify interactions.

The computer program MANCAN described in Section 4 was used to assist in these calculations. Each of the variables presented in Table 2-3 is discussed in Section 3 with regard to the effect on program cost.

Table 2-2

Manufacturing Cost Assumptions

Materials	Costs
Aluminum Sheet	$ .68/lb*
Adhesive for Bonding	1.00/sq. ft.*
Honeycomb (Fiberglass)	20.00/cu. ft.
Extrusions (Y Rings and Cylinder Rings)	4.00/ft.
Inspection	
X-Ray Weld	$ 5.50/sq. ft.*
	2.00/ft.*
Sonic Inspection	5.50/sq. ft.*
Facilities & Tooling**	
All costs for required facilities and tooling are included as a non-recurring expense.	
Taxes, Interest, and Depreciation	
Total manufacturing program costs include: a. The amount of depreciation of tooling and facilities and assume that the tooling and facilities are sold for depreciated value at the end of the manufacturing program b. As applicable interest on capital invested in tooling and facilities at the rate of 6% of **invested** value per year of program length. c. As applicable, property taxes on facilities and tooling equal 3% of depreciated value per year of program length.	
Fabrication	
Metal Removal	
Numerical Controlled Milling	$ 1.50/lb.*
Chem Mill	5.50/lb.*
Tig Welding	7.00/ft.*
Labor Rate ***	
Pre-Manufacturing	$15.00/hr.
Manufacturing (Includes All Shop Personnel)	15.00/hr.
Quality Control (Includes Manufacturing Test)	15.00/hr.
Material Constraint	
All Materials in Elements 1 and 2 are Aluminum Alloys with the exception of some fasteners.	
Recycle Due to Changes	
A 40 percent recycle of all pre-manufacturing operations (planning, scheduling, etc.), was included to account for impact of changes. This assumes that 40 percent of all planning and manufacturing engineering work would be done over to correct for changes during the manufacturing cycle.	
Land	
(Various prices were assumed for land, depending on location.) Daytona Beach Vicinity—$12,000/Acre Cape Kennedy Vicinity—$14,500/Acre Philadelphia Vicinity—$35,000/Acre	
Factory/Building Space	
(Assumed prices varied depending on usage, ceiling height.) Low Bay Ordinary Shop (30 Foot)—$18/sq. ft. Composite Factory and Engineering—$25/sq. ft. High Bay Assembly (100 Foot)—$60/ft.	

NOTES:

Cost Basis—All costs including tax rates and interest on capital invested in facilities and tooling are based on 1969 values and are shown without fee. Interest and tax rates are based upon those prevalent in Volusia and Brevard Counties, Florida (Daytona Beach/Cape Kennedy vicinity).

* —Data from Reference 1.

** —Data from Reference 2.

*** —Labor rates include direct labor charges and overhead and G&A expenses, including proportionate share of cost of operating and maintaining the buildings and tools, heat, light, water, services, consumable supplies, IR&D, documentation, etc.

Table 2-3

Study Variables

Variable	Number of Observations
1. Type of Structure (Size, Pressurized vs. Non-Pressurized, Manned vs. Unmanned)	2 Structures
2. Rate of Production (2/Year, 20/Year)	2 Rates
3. Quantity Produced (1,4,10,20,100)	Average of 3 Quantities
4. State of the Art (Mfg. Technology Differences)	3 Lines
5. Cost Elements (Areas) (Facilities, Tooling, Pre-Manufacturing, Manufacturing)	4 Areas
6. Cost Elements (Labor Type) (Material, Mfg. QC, Total)	4 Types
7. Plant Location (Transportation, Separation)	2 Locations
8. Learning Curves (100 percent, 80 percent)	2 Values
9. Detail Steps in Fabrication, Inspection	~ 80 Steps
10. Factors Variation (Design Tolerances, Changed Specs, Change Control, Improved Scheduling, etc.)	~ 20 Factors
11. Facility and Tooling Depreciation (100 percent write-off, straight-line, sum of the years digits)	3 Rates
12. Taxes and Interest for Facilities and Tooling (None, 3 percent tax—6 percent interest)	2 Values

SECTION 3

RESULTS AND CONCLUSIONS

3.1 INTRODUCTION

Results were determined by a detailed evaluation of the cost impact of changes to the variables in Table 2-3. These variables were studied one-at-a-time and in multiple combinations to determine their influence or manufacturing cost.

These results are presented herein, first from an overall viewpoint and then in order following that of Table 2-3. Distributions of cost grouping by the functions listed in Table 3-1 are tabulated in Section 3.3, followed by presentation of results from the interactions study for multiple variations of program factors. Additional interaction study results are given in Section 6.

Section 3 is concluded with a subsection of conclusions and recommendations for future studies.

3.2 DISCUSSION OF OVERALL COST DISTRIBUTION AND PROGRAM VARIABLES

3.2.1 OVERALL COST DISTRIBUTION

The total cost distribution is shown graphically for the three manufacturing lines in Figures 3-1 through 3-4 for various assumptions of depreciation, taxes, interest, and other factors. Figures 3-1 and 3-2 show the cost distribution for the frustum structure (Element 1) for manufacturing lines designed for production rates of 2 per year and 20 per year, respectively. Figures 3-3 and 3-4 show the analogous results for the propellant tank structure (Element 2).

The cost distribution is further subdivided within each bar as noted by the shaded areas to indicate the magnitude of costs for the major cost groups.

The first bar of each manufacturing line graph is the base (or nominal) case which serves as a basis of comparison and assumes 100 percent writeoff of facilities and tooling at the end of the program.

Table 3-1

Grouping of Like Activities Into Identifiable Cost Groups

Identification	Cost Groups	Items Included in Cost Groups
Raw Material	M1	Sheet Aluminum, honeycomb, rivets
In-Process Material	M2	Bonding Cement, Die Penetrant, Maskant
Inspect Dimension Form	I1	Mechanical Inspect, X-Ray
Weld, Bond	I2	X-Ray, Die Penetrant, Ultra-sonic
ASM, Other	I3	Visual, Optical, Mechanical
Machining	S1	Trimming, Cutting, Milling, Drilling, Sawing, Machining
Forming	S2	Stretch-form, Brake-form, Bending
Joining	S3	Welding, Brazing
Tooling, Material Handling	T1	Spreader Bars, Dollies, Load Cells
Jigs, Fixtures	T2	Templates, Dies, Hydrostatic Test Equipment, De-greaser Tank Assembly Tower, Pressure Test Equipment
Test-Accept	A1	Acceptance Testing, Pressure (Leak) Testing
Storage	D1	Storage, Stock Room
Transport	D2	Drayage, Moving on Mobile Fixture, Dollies, Shipping, Air-Cargo
Facilities Bldg.	F1	Bricks and Mortar, Partitions, Work Stands
Mach Tools	F2	Heat Treat, Etch, Clean and Mill, X-Ray, Weld Head, Presses
Processing	P1	Any other processing not included above
Chem Mill, Anneal Heat Treat, Curing		
Pre-Manufacturing Labor	L1	Near Term Pre-Manufacturing Operations Non-Recurring Cost Including 40 Percent Recycle Plus Recurring Cost Per Unit Manufactured

Line No.	1	1	1	1	2	2	2	2	3	3	3	3
Depreciation	100%	100%	SL	SL	100%	100%	SL	SL	100%	100%	SL	SL
Learn Curve	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Taxes (Local)	0	3%	3%	3%	0	3%	3%	3%	0	3%	3%	3%
Interest	0	6%	6%	6%	0	6%	6%	6%	0	6%	6%	6%
Changes to Factors	0	0	0	4+8	0	0	0	4+8	0	0	0	4-8

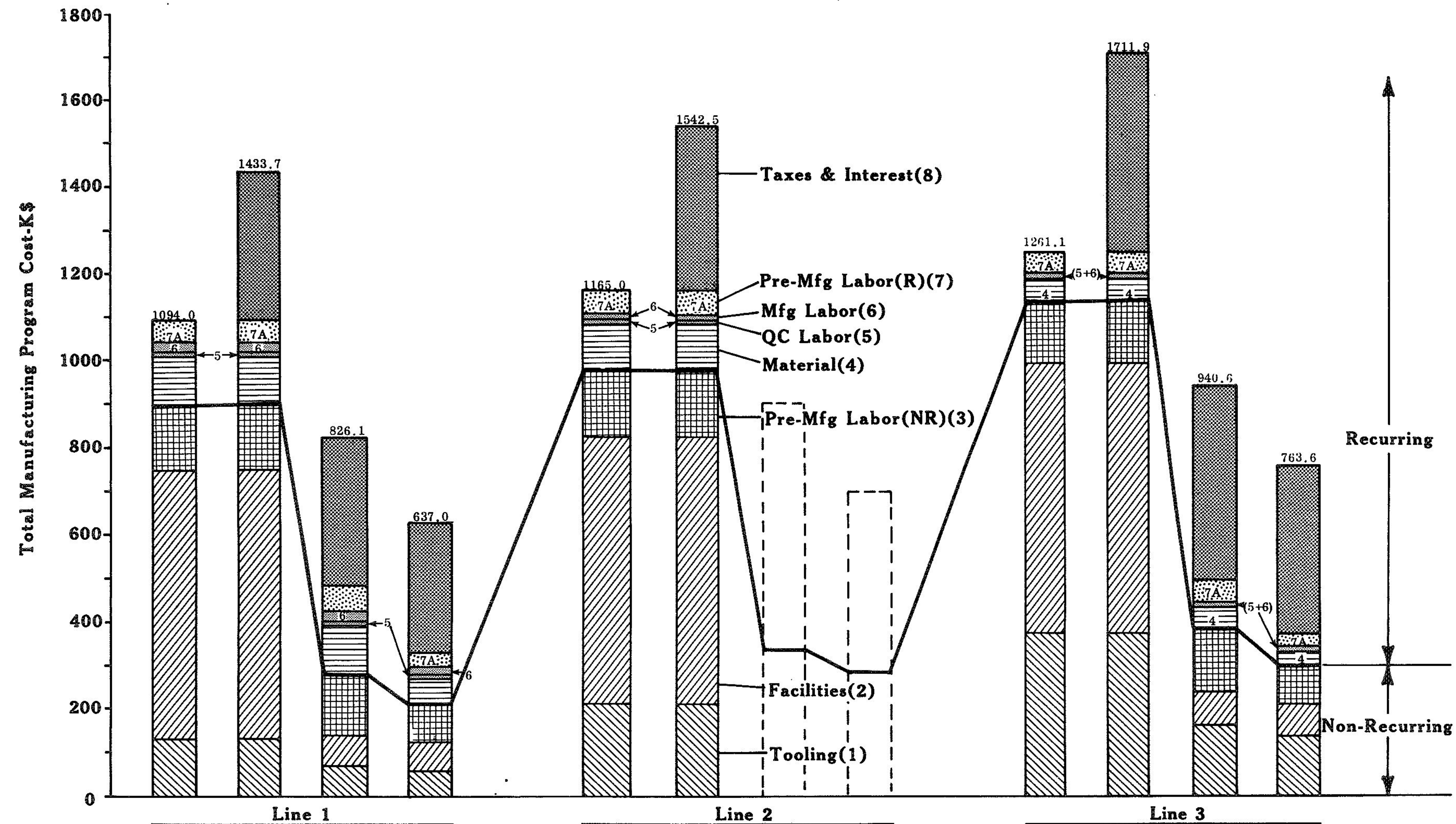


Figure 3-1. Manufacturing Cost Distribution for the Support Frustum Structure (Element No.1) for 2/Year Production for 5 Years

Line No.	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3
Depreciation	100%	100%	SL	SL	SL	100%	100%	SL	SL	SL	100%	100%	SL	SL	SL
Learning Curve	100%	100%	100%	80%	80%	100%	100%	100%	80%	80%	100%	100%	100%	80%	80%
Taxes (Local)	0	3%	3%	3%	3%	0	3%	3%	3%	3%	0	0	3%	3%	3%
Interest	0	6%	6%	6%	6%	0	6%	6%	6%	6%	0	6%	6%	6%	6%
Changes to Factors	0	0	0	0	4+8	0	0	0	0	4+8	0	0	0	0	4+8

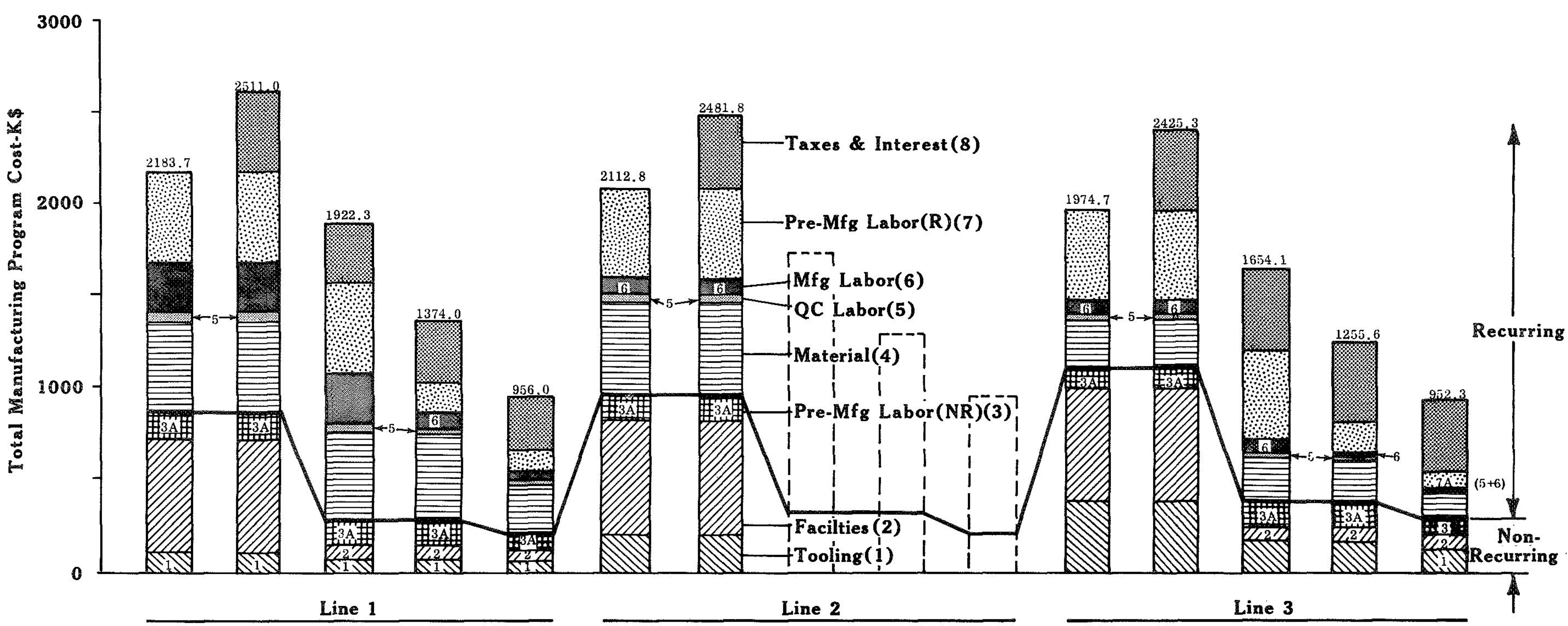


Figure 3-2. Manufacturing Cost Distribution for the Support Frustum Structure (Element No. 1) and 20/Year for 5 Years

Line No.	1	1	1	1	2	2	2	2	3	3	3	3
Depreciation	100%	100%	SL	SL	100%	100%	SL	SL	100%	100%	SL	SL
Learning Curve	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Taxes (Local)	0	3%	3%	3%	0	3%	3%	3%	0	3%	3%	3%
Interest	0	6%	6%	6%	0	6%	6%	6%	0	6%	6%	6%
Changes to Factors	0	0	0	4+5+8	0	0	0	4+5+8	0	0	0	4+5+8

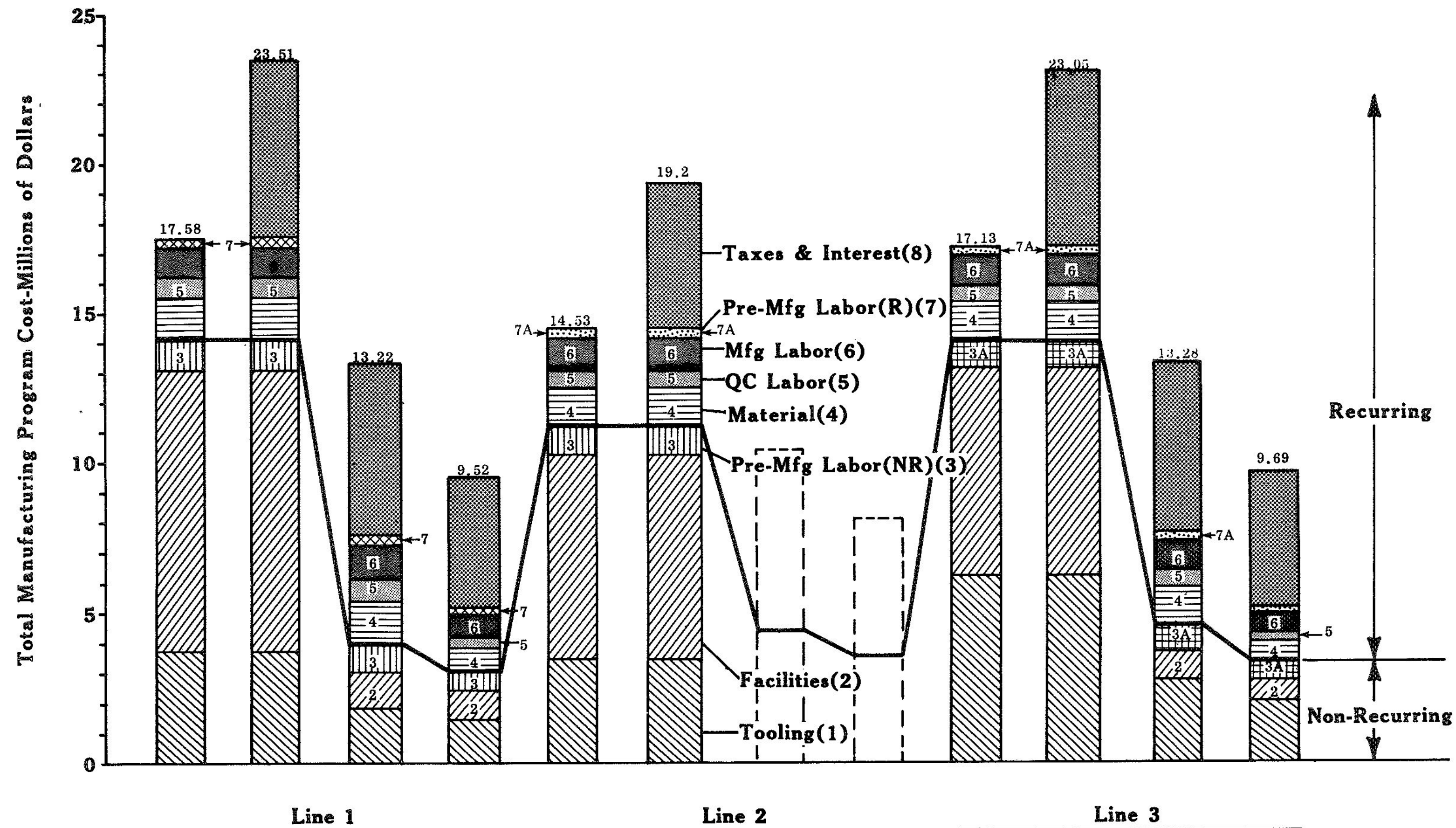


Figure 3-3. Manufacturing Cost Distribution for the Propellant Tank Structure (Element No. 2) and 2/Year Production for 5 Years

Line No.	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3
Depreciation	100%	100%	SL	SL	SL	100%	100%	SL	SL	SL	100%	100%	SL	SL	SL
Learning Curve	100%	100%	100%	80%	80%	100%	100%	100%	80%	80%	100%	100%	100%	80%	80%
Taxes(Local)	0	3%	3%	3%	3%	0	3%	3%	3%	3%	0	3%	3%	3%	3%
Interest	0	6%	6%	6%	6%	0	6%	6%	6%	6%	0	6%	6%	6%	6%
Changes to Factors	0	0	0	0	4+5+8	0	0	0	0	4+5+8	0	0	0	0	4+5+8

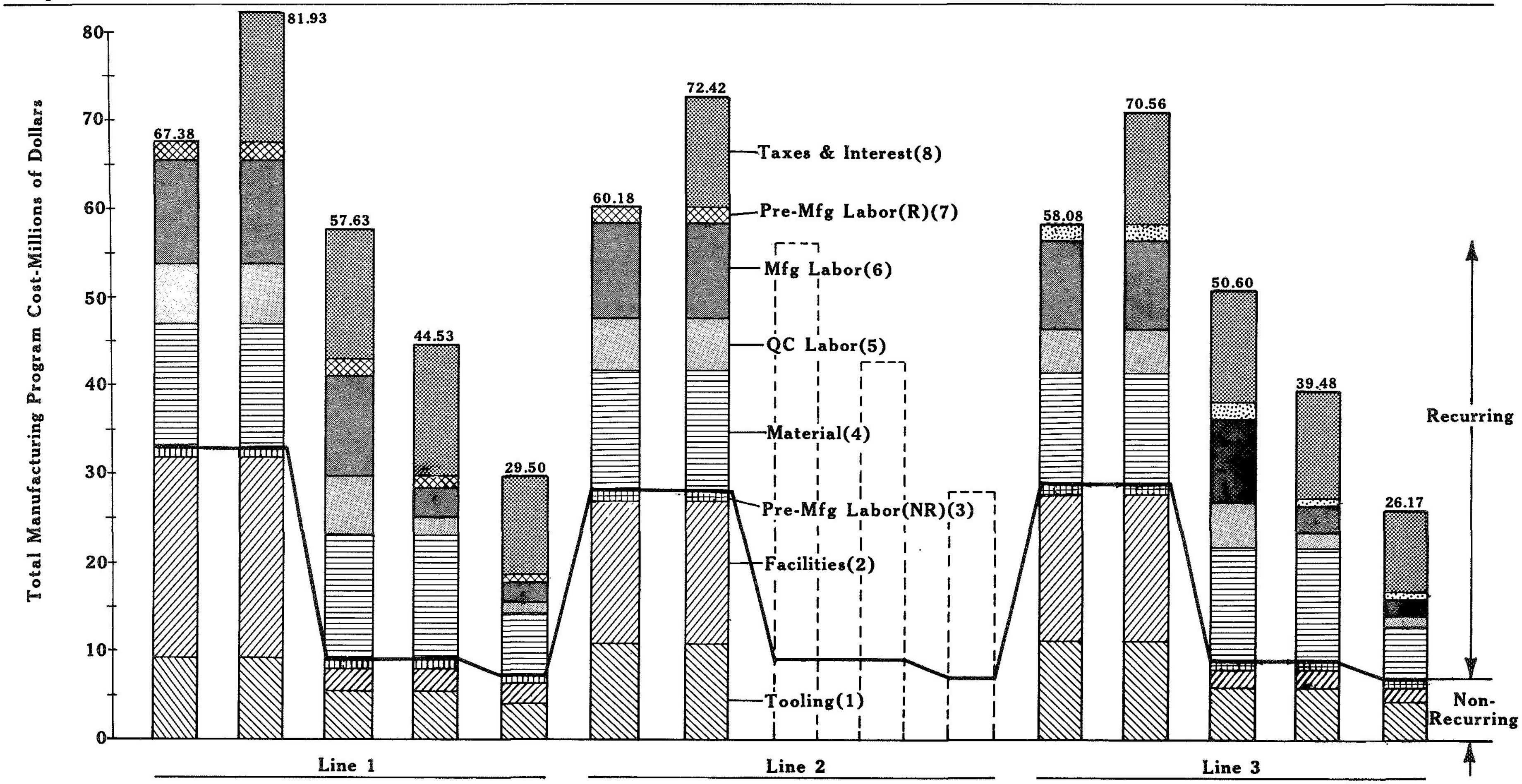


Figure 3-4. Manufacturing Cost Distribution for the Propellant Tank Structure (Element No.2) and 20/Year Production for 5 Years

The second bar includes the taxes and interest on capital in addition to the 100 percent writeoff assumption. The third bar incorporates the straight line depreciation assumption for the two per year production rate cases, and the fourth bar includes a combination of certain changes to the basic manufacturing lines in addition to the straight line depreciation, taxes and interest. The latter two or three bars are shown by dashed lines for manufacturing line 2 because this data is based on data interpolated between lines 1 and 2 rather than on detailed computer program runs.

For the 20 per year production rate cases (Figures 3-2 and 3-4) the fourth bar on the graph includes the effect of an 80 percent learning curve on the recurring labor costs. The fifth bar includes the effect of combining the specific changes in addition to the learning curve.

A summary of the unit costs for the twelve nominal lines (3 lines, 2 production rates, 2 elements) is shown in Table 3-2. These unit costs correspond to the first bar of each of the graphs in Figures 3-1 through 3-4. The data presented in the bar graphs are given in tabular form in Tables 3-3 through 3-6.

Table 3-2

Unit Manufacturing Cost—K$/Unit

		State of the Art Line No. 1 Baseline	Improved Technology Line No. 2	Advanced Technology Line No. 3
Frustum (Element No. 1)	10 Units at 2/Year	$ 109.4 (100%)	$ 116.5 (106.4%)	$ 126.1 (115.2%)
	100 Units at 20/Year	21.8 (100%)	21.1 (96.7%)	19.7 (90.3%)
Tank (Element No. 2)	10 Units at 2/Year	$1757.6 (100%)	$1453.8 (82.7%)	$1713.2 (97.4%)
	100 Units at 20/Year	673.7 (100%)	601.8 (89.3%)	580.8 (86.2%)

Influence of the major variables, listed in Table 2-3, is discussed in the following paragraphs.

Table 3-3

Manufacturing Cost Distribution for Element No. 1 and a Product Capability of 2 per Year—5 Year Program

Run No.	10	139	142	145	30	205	50	148	151	154
Line No.	1	1	1	1	2	2	3	3	3	3
Depreciation	100%	100%	SL	SL	100%	100%	100%	100%	SL	SL
Learning Curve	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Taxes (Property) Local	0	3%	3%	3%	0	3%	0	3%	3%	3%
Interest on Capital Invested in Tooling and Facilities	0	6%	6%	6%	0	6%	0	6%	6%	6%
Changes to Factors	0	0	0	4+8	0	0	0	0	0	4+8
Cost Item	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$
Taxes & Interest	0	339	333	296	0	378	0	451	438	391
Pre-Mfg Labor (R) Transportation (R)*	50	50	50	32	50	50	50	50	50	32
Mfg Labor	28	28	27	20	14	14	7	7	7	6
QC Labor	5	5	5	3	5	5	3	3	3	2
Material—Raw Material—Inprocess Subcontracted Components	112	112	112	63	113	113	55	55	55	31
Pre-Mfg Labor (NR) Transportation (NR)*	145	145	145	93	145	145	145	145	145	93
Facilities	620	620	77	70	620	620	620	620	78	70
Tooling	135	135	77	61	219	219	382	382	165	140
Total Program Cost (10 Elements)	1094	1434	826	637	1165	1543	1261	1712	941	764

*Line 1, Element 2 Only

Table 3-4

Manufacturing Cost Distribution for Element No. 1 and a Product Capability of 20 per Year—5 Year Program

Run No.	20	31A	39	44	133	40	199	60	104	107	110	136
Line No.	1	1	1	1	1	2	2	3	3	3	3	3
Depreciation	100%	100%	SL	SL	SL	100%	100%	100%	100%	SL	SL	SL
Learning Curve	100%	100%	100%	80%	80%	100%	100%	100%	100%	100%	80%	80%
Taxes (Property) Local	0	3%	3%	3%	3%	0	3%	0	3%	3%	3%	3%
Interest on Capital Invested in Tooling and Facilities	0	6%	6%	6%	6%	0	6%	0	6%	6%	6%	6%
Changes to Factors	0	0	0	0	4+8	0	0	0	0	0	0	4+8
Cost Item	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$
Taxes & Interest	0	327	321	321	285	0	369	0	450	438	438	391
Pre-Mfg Labor (R) Transportation (R)*	495	495	495	162	103	495	495	495	495	495	162	103
Mfg Labor	274	274	274	89	65	105	105	70	70	70	23	18
QC Labor	45	45	45	15	8	42	42	27	27	27	9	5
Material—Raw Material—Inprocess Subcontracted Components	497	497	497	497	278	505	505	236	236	236	236	132
Pre-Mfg Labor (NR) Transportation (NR)*	145	145	145	145	93	145	145	145	145	145	145	93
Facilities	620	620	78	78	70	620	620	620	620	78	78	70
Tooling	107	107	67	67	53	200	200	382	382	165	165	140
Total Program Cost (100 Elements)	2184	2511	1922	1374	956	2113	2482	1975	2425	1654	1256	952

*Line 1, Element 2 Only

Table 3-5

Manufacturing Cost Distribution for Element No. 2 and a Product Capability of 2 per Year—5 Year Program

Run No.	70	95	98	157	90	202	110	160	163	166
Line No.	1	1	1	1	2	2	3	3	3	3
Depreciation	100%	100%	SL	SL	100%	100%	100%	100%	SL	SL
Learning Curve	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Taxes (Property) Local	0	3%	3%	3%	0	3%	0	3%	3%	3%
Interested on Capital Invested in Tooling and Facilities	0	6%	6%	6%	0	6%	0	6%	6%	6%
Changes to Factors	0	0	0	4, 5+8	0	0	0	0	0	4, 5+8
Cost Item	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$
Taxes & Interest	0	5932	5792	4635	0	4666	0	5926	5748	4598
Pre-Mfg Labor (R) Transportation (R)*	189	189	189	121	150	150	150	150	150	96
Mfg Labor	1131	1131	1131	734	1094	1094	1018	1018	1018	672
QC Labor	664	664	664	335	589	589	519	519	519	262
Material—Raw Material—Inprocess Subcontracted Components	1418	1418	1418	715	1370	1370	1309	1309	1309	660
Pre-Mfg Labor (NR) Transportation (NR)*	992	992	992	636	968	968	968	968	968	620
Facilities	9384	9384	1173	950	6972	6972	6972	6972	871	705
Tooling	3798	3798	1871	1393	3396	3396	6196	6196	2697	2080
Total Program Cost (10 Elements)	17576	23508	13229	9518	14538	19204	17132	23058	13281	9692

*Line 1, Element 2 Only

Table 3-6

Manufacturing Cost Distribution for Element No. 2 and a Product Capability of 20 per Year—5 Year Program

Run No.	8D	7A	15	20	120	10D	189	12D	116	119	121	124
Line No.	1	1	1	1	1	2	2	3	3	3	3	3
Depreciation	100%	100%	SL	SL	SL	100%	100%	100%	100%	SL	SL	SL
Learning Curve	100%	100%	100%	80%	80%	100%	100%	100%	100%	100%	80%	80%
Taxes (Property) Local	0	3%	3%	3%	3%	0	3%	0	3%	3%	3%	3%
Interest on Capital Invested in Tooling and Facilities	0	6%	6%	6%	6%	0	6%	0	6%	6%	6%	6%
Changes to Factors	0	0	0	0	4, 5+8	0	0	0	0	0	0	4, 5+8
Cost Item	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$	Cost K$
Taxes & Interest	0	14548	14232	14232	11324	0	12235	0	12482	12176	12176	9667
Pre-Mfg Labor (R) Transportation (R)*	1890	1890	1890	880	566	1500	1500	1500	1500	1500	490	313
Mfg Labor	11305	11305	11306	3691	2396	10940	10940	9932	9932	9932	3243	2136
QC Labor	6641	6641	6641	2168	1093	5889	5889	5078	5078	5078	1658	836
Material—Raw Material—Inprocess Subcontracted Components	14182	14182	14182	14182	7148	13697	13697	12863	12863	12863	12863	6483
Pre-Mfg Labor (NR) Transportation (NR)*	1040	1040	1040	1040	667	968	968	968	968	968	968	620
Facilities	22833	22833	2854	2854	2312	16680	16680	16680	16680	2085	2085	1689
Tooling	9496	9496	5492	5492	3999	10510	10510	11060	11060	6002	6002	4428
Total Program Cost (100 Elements)	67388	81936	57636	44539	29504	60183	72418	58080	70562	50603	39484	26171

*Line 1, Element 2 Only

3.2.2 TYPE OF STRUCTURE

Two widely diverse types of aluminum aerospace structures were studied, One was a relatively high-production, smaller diameter frustum, which was unpressurized and for use in unmanned operations. The second structure was a larger, pressurized tank, designed for use in manned operations.

In general, results observed for each structure are similar—though some differences were noted and are discussed later. The principal impacting factors related to type of structure are associates to the differences of pressurization or nonpressurization. Higher manufacturing costs are reflected in the pressurized propellant tank structure since joints are welded rather than riveted as in the case of the support frustum. The welded pressurized joints require shop environmental control, complex welding equipment, tooling, safety and inspection procedures and acceptance testing. The nonpressurized frustum structure is riveted together. Frequently the final inspection of a riveted joint is entirely visual whereas that of a welded joint may require a sample welded specimen every time the "torch is lit" in addition to requiring weld grinding, 200 percent X-ray, dye penetrant inspection, and pressure testing.

3.2.3 RATE OF PRODUCTION

Production rates of two and twenty major structures per year for up to five years are low when compared with the production of airplanes or automobiles; however, these production rates do bracket the Saturn V and other major space hardware programs.

Production rates and program length are factors that significantly impact element cost since they are pertinent to the defining and establishment of the cost of facilities and tooling and in turn, expected property taxes, interest on capital, and the type depreciation writeoff most appropriate to the program. At the low production rate, cost of facilities and tooling including taxes and interest, and other nonrecurring items for a large pressurized structure could be 74 to 87 percent of the total manufacturers program cost and at the high production rate, 40 to 63 percent of the total manufacturers cost. For the nonpressurized smaller structure, these percentages range at the low production rate from 74 to 94 percent and 40 to 73 percent for the high or production rate.

3.2.4 QUANTITY PRODUCED

No single factor has a greater impact on unit cost than the quantity of like elements produced. For example, with a production capability of 20 elements per year, the manufacturing cost of each element when producing 100 is less than 7 percent the cost of producing one element. With a production rate of 2 elements per year, the manufacturing cost of each element when producing 10 is in the order of 15 to 36 percent the cost of producing one element. These significant reductions in manufacturing cost are the result of nonrecurring cost amortization and reduction in recurring cost resulting from improved job learning.

3.2.5 MANUFACTURING TECHNOLOGY DIFFERENCES

With the relatively low production rates of aerospace hardware program, advances in manufacturing technologies are more likely to improve quality and reliability than reduce manufacturing cost. The application of automated machine tools, utilizing the line 3 consolidated facilities, elementary interplant transportation, and the use of new and improved processes result in the reduction of up to 60 percent in the number of major parts and the elimination of up to 40 percent of the welded joints. The element number 2 manufacturing cost at the low production rate remains essentially unchanged and is decreased by 7 to 19 percent at the higher production rates.

For both elements, the unchanged or increased cost at the low production rates and the small savings (if any) at the higher production rates is attributed to the increases in nonrecurring costs, primarily, tooling.

Improvements in quality and reliability through the application of these new technologies while not quantifiable at this time should be significant. For example, improvements in element number 2 in reducing welding would improve quality, reduce possibilities of leakage and increase payload by 325 pounds. If this payload were worth $1000 per pound, then the overall value would increase by 21 to 62 percent over the line number 1 value.

Table 3-7

Increased Value in K$ for Payload Increase Associated With Technology Improvements from Line No. 1 to Line No. 3

	Baseline Cost (Line No. 1)	Manufacturing Δ Savings	Payload Δ Worth (For $1000/lb)	Total Δ Worth
10 Units at 2/Year	$1757.6 (100%)	$ 44.4 (2.6%)	$ 325 (18.4%)	$ 369.4 (21%)
100 Units at 20/Year	$ 673.7 (100%)	$ 92.9 (13.7%)	$ 325 (48.2%)	$ 417.9 (62%)

3.2.6 NONRECURRING COST ELEMENTS

The costs include facilities, machine tools, jigs and fixtures, and premanufacturing labor. At the lower production rates, the results of the study indicated that for a five-year state-of-the-art manufacturing line program, the nonrecurring cost plus applicable taxes and interest amount to 74 to 87 percent of the total manufacturing cost and 77 to 93 percent for an advanced line program.

Compared to this, a five-year state-of-the-art manufacturing program at the higher production rates has nonrecurring cost plus applicable taxes and interest of 32 percent to 62 percent and for an advanced line program 42 percent to 72 percent.

These percentages show the importance of quantity produced since fixed (nonrecurring) costs are amortized over the total output. Indication given by the increasing percentages with the advanced technologies are that higher production is of even greater importance in holding unit element cost to a minimum. Increases in nonrecurring cost of the advanced lines are related to the increasing cost of automated and larger, more complex machine tools.

These nonrecurring costs, considering the generally low production rates of recent and current programs, are a significant area for further study for cost reductions.

3.2.7 RECURRING COST ELEMENTS

These costs include all manufacturing, quality control, and recurring "premanufacturing" labor, fabrication material cost, and expendable material such as X-ray films, inspection materials, welding rod, etc. For the low production rates, recurring costs for a five-year program are small, ranging from 6 to 26 percent. For the higher production rates, the recurring cost range from 30 to 70 percent of total program cost. The recurring cost area, as production rates approach something in the order of 20 elements per year, is a significant area for potential cost reductions.

3.2.8 PLANT LOCATION

Results of industrial surveys conducted during the Phase I portion of the study show that the aerospace corporation assembly function is generally geographically separated from the detailed fabrication and subassembly function. Results of this study indicate that for a separation of one hundred miles between the assembly plant and detail fabrication and subassembly plant, transportation cost over that of a consolidated facility amount to about one percent of the total manufacturing program cost.

Other cost factors to be considered in relation to plant location is the skilled manpower availability, construction cost, local taxes, mode of transportation available, and time in transit from assembly to test or launch area.

Training programs are very expensive. To train 50 percent of the work force, it is estimated that unit element costs increase in the order of 30 percent with a probable additional four-percent increase in cost for limited skill workers error corrections. Construction costs vary widely throughout the nation; construction labor costs and total construction costs have spreads of more than 30 percent from one location to another. Because of the size of the finished product, location near waterways or airports may have a significant transportation advantage since overland transportation has many restrictions such as tunnel and overpass clearances, roadwidths and load capacity.

Time in transit from assembly to test or launch can be costly since the product represents invested money, and interest must be paid during transit time as well as any other time.

3.2.9 LEARNING CURVES

Learning curves showing planned cost reductions are generally applied to production rates of an estimated 8 to 10 elements per year or more. One Apollo contractor stated that his learning curve was a horizontal line, and that he was actually building several different structures rather than several copies of the same structure even though outward appearance was the same. He further indicated that changes being incorporated were a big contributor to keeping the learning curve horizontal.

The results in Figures 3-1 through 3-4 show the application of "cost reduction" learning curves to the 20 per year production rate. At this production rate for a period of five years, the 80 percent curve shows a manufacturing program cost reduction of approximately 13 to 30 percent for the state-of-the-art, improved, and advanced manufacturing lines. This reduction is significant and can be achieved by holding down changes and thorough manufacturing planning.

3.2.10 DETAILS OF FABRICATION AND INSPECTION

Each manufacturing process step must be carefully defined and documented to assure that no guess work is necessary for the worker to do his job and to assure conformity with all specifications. Materials and labor costs are 18 to 25 percent of total manufacturing cost for the state-of-the-art lines and 9 to 23 percent for the advanced lines at the low production rates for a five year program and 50 to 70 percent of total manufacturing cost for the state-of-the-art lines and 42 to 58 percent for the advanced lines at the higher production rate. Tooling costs in percent of manufacturing program cost increased in the order of 5 to 15 percent in going from the state-of-the-art to the advanced manufacturing line for both production rates. This increase in tooling cost as processes are automated, is generally offset to some degree by decrease in labor and material costs.

3.2.11 DEPRECIATION METHODS, TAXES AND INTEREST

The basic manufacturing lines and their respective cost include the assumption that equipment and facilities depreciate to "0" value at the end of the defined manufacturing program and taxes on these equipments and facilities are not considered.

As the study progressed, it became apparent that the nonrecurring portion of the total cost was very significant and that methods of depreciation as well as the taxes and interest aspect should be considered for a more realistic picture. As a result, analyses in these areas looked at both straight line and sum of the digits depreciation methods and property taxes consistent with Eastern Volusia County, Florida (3 percent = $30 assessment per $1000 of valuation) and interest on principle invested of six percent. The impact of these types of factors upon manufacturing costs are indicated by Figures 3-5 and 3-6 where the cost distributions are shown pictorially to illustrate the effect of taxes and interest and depreciation method upon the total program cost. The two figures present the two extremes of the problem as related to the nonrecurring/recurring cost breakdown. For example, the data in Figure 3-5 reflects the assumption that there is a 100-percent writeoff on facilities and tooling at the end of the five-year program. For the low production rate program the nonrecurring costs are about 60 percent of the total cost and if the taxes and interest cost on the facilities are included this boosts the fixed costs to a level of approximately 85 percent of total costs. The corresponding numbers for the higher production rate are approximately 37 percent and 53 percent respectively. This emphasizes the importance of the fixed cost area as a potential area for cost reduction where the facilities and tooling are totally written off (100 percent) against the job.

The other extreme is represented by the data given in Figure 3-6 where the results are based on the straight line depreciation method. This assumes that only the yearly depreciation is accumulated for the total program length and charged off as the facilities and tooling costs. Figure 3-6 shows that for the low production rate even with the

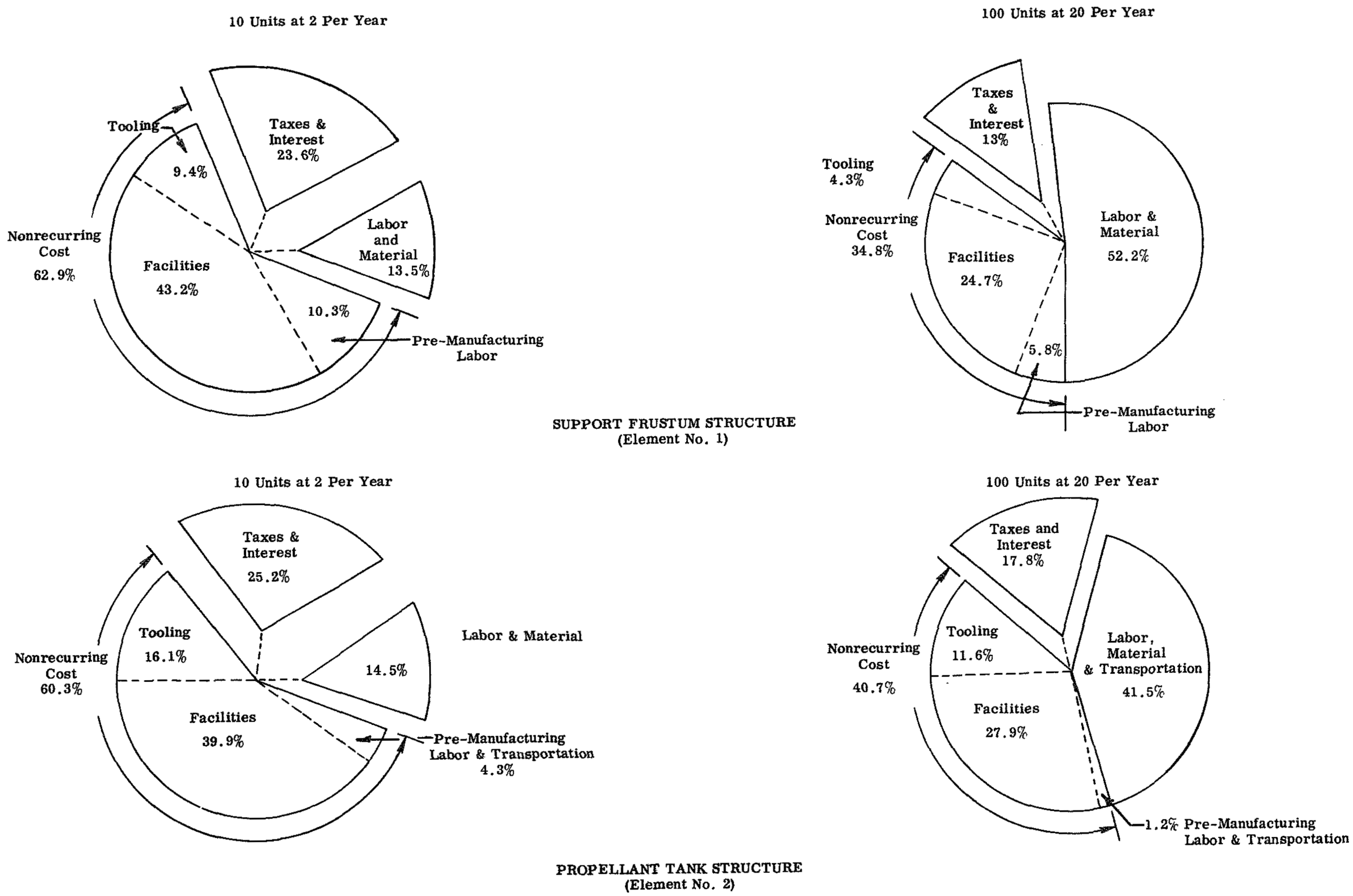


Figure 3-5. Cost Distribution for the State-of-the-Art Manufacturing Lines (Line 1) Including 100 percent Depreciation Method

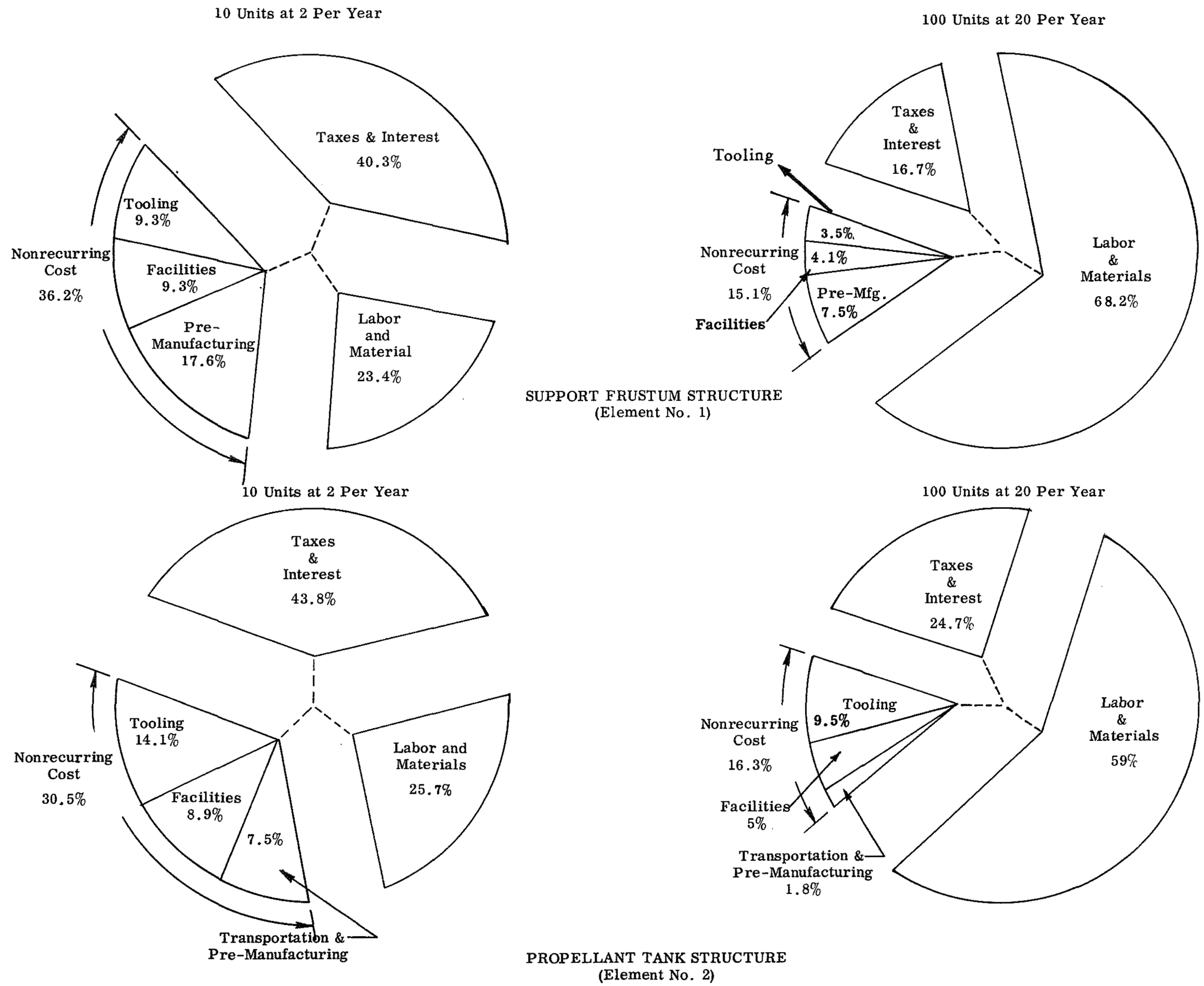


Figure 3-6. Cost Distribution for the State-of-the-Art Manufacturing Line (Line 1) Including Straight Line Depreciation Method

straight line depreciation method the nonrecurring cost plus taxes and interest are about 75 percent of the total cost. This decreases to 30 to 40 percent for the 20 per year rate.

3.3 COST GROUPING

The total manufacturing program has been subdivided into 17 functional cost groups. Each of these cost groups has been given a symbolic designation. Table 3-8 shows this cost group breakdown. As an example, cost group Number 1 is designated M1 which designates the raw and supplied material cost. Tables 3-8 through 3-11 present the cost group breakdown in dollars and percent of total cost for each of the three lines for both structural elements 1 and 2 utilizing both production rate capabilities (2 per year and 20 per year). All of the data is based on a five year program and full depreciation (100 percent writeoff) is assumed at the end of the program.

Results are also shown in the major categories of Tooling, Facilities, Transportation, Materials and Labor. The Labor is separated into premanufacturing, quality control, and manufacturing labor. This is the type of output used for the Manufacturing Cost Analysis (MANCAN) computer program developed during the study. Tables 3-12 and 3-13 give a summary of the cost distributions in both dollars and percent of toal cost among these categories for the base lines.

Table 3-8

Distribution of Cost by Cost Group
For the Support Frustum Structure (Element No. 1)
Rate = 2 per Year, Program Length = 5 Years

Line ⟶			State of the Art (Line 1)		Improved (Line 2)		Advanced (Line 3)	
Cost Group		Cost Group Title	Program Cost		Program Cost		Program Cost	
No.	Designation		K$	% of Total	K$	% of Total	K$	% of Total
1	M 1	Raw Material	111.0	10.2	110.5	9.5	54.7	4.3
2	M 2	In-Process Material	1.1	0.1	2.3	0.2	0.4	-
3	I 1	Inspect - Form, Dimen.	1.3	0.1	1.4	0.1	0.7	0.1
4	I 2	Inspect - Weld, Bond	0	-	1.2	0.1	0.9	0.1
5	I 3	Inspect - Assem., Other	3.1	0.3	2.2	0.2	1.1	0.1
6	S 1	Machining	7.3	0.6	7.4	0.6	3.4	0.3
7	S 2	Forming	0.9	0.1	1.0	0.1	0.3	-
8	S 3	Joining	17.7	1.6	2.9	0.3	1.3	0.1
9	T 1	Tooling, Material, Handling	0.3	-	0.2	-	0	-
10	T 2	Jigs and Fixtures	43.8	4.0	44.9	3.9	45.0	3.5
11	A 1	Test - Accept	0	-	0	-	0	-
12	D 1	Storage	0.5	0.1	0	-	0	-
13	D 2	Transport	0	-	0	-	0	-
14	F 1	Facilities - Buildings	620.0	56.7	620.0	53.2	620.0	49.2
15	F 2	Furnaces and Machine Tools	90.7	8.3	173.7	14.9	336.5	26.7
16	P 1	Processing - Chem Mill, Anneal, Cure	1.5	0.1	2.5	0.2	2.0	0.2
17	L 1	Pre-Manufacturing Labor	194.8	17.8	194.8	16.7	194.8	15.4
		Total	1094.0	100.0	1165.0	100.0	1261.1	100.0

Table 3-9

Distribution of Cost by Cost Group
For the Support Frustum Structure (Element No. 1)
Rate = 20 per Year, Program Length = 5 Years

Line →			State of the Art (Line 1)		Improved (Line 2)		Advanced (Line 3)	
Cost Group		Cost Group Title	Program Cost		Program Cost		Program Cost	
No.	Designation		K$	% of Total	K$	% of Total	K$	% of Total
1	M 1	Raw Material	485.6	22.2	479.6	22.7	231.6	11.7
2	M 2	In-Process Material	11.5	0.5	25.6	1.2	4.5	0.2
3	I 1	Inspect - Form, Dimen.	13.8	0.6	8.7	0.4	6.9	0.4
4	I 2	Inspect - Weld, Bond	0	-	12.0	0.6	9.0	0.5
5	I 3	Inspect - Assem., Other	31.3	1.4	21.5	1.0	10.7	0.5
6	S 1	Machining	73.5	3.4	48.3	2.3	34.5	1.8
7	S 2	Forming	7.2	0.3	3.1	0.2	2.4	0.1
8	S 3	Joining	177.0	8.1	30.0	1.4	13.5	0.7
9	T 1	Tooling, Material, Handling	0.3	-	0.2	-	0	-
10	T 2	Jigs and Fixtures	44.7	2.1	54.3	2.6	45.0	2.3
11	A 1	Test - Accept	0	-	0	-	0	-
12	D 1	Storage	1.3	0.1	0	-	0	-
13	D 2	Transport	0	-	0	-	0	-
14	F 1	Facilities - Buildings	620.0	28.4	620.0	29.3	620.0	31.4
15	F 2	Furnaces and Machine Tools	62.2	2.9	145.6	6.9	336.5	17.0
16	P 1	Processing - Chem Mill, Anneal, Cure	15.0	0.7	23.7	1.1	19.8	1.0
17	L 1	Pre-Manufacturing Labor	640.3	29.3	640.3	30.3	640.3	32.4
		Total	2183.7	100.0	2112.8	100.0	1974.7	100.0

Table 3-10

Distribution of Cost by Cost Group
For the Propellant Tank Structure (Element No. 2)
Rate = 2 per Year, Program Length = 5 Years

Line →			State of the Art (Line 1)		Improved (Line 2)		Advanced (Line 3)	
Cost Group		Cost Group Title	Program Cost		Program Cost		Program Cost	
No.	Designation		K$	% of Total	K$	% of Total	K$	% of Total
1	M 1	Raw Material	410.0	2.3	371.0	2.6	380.0	2.2
2	M 2	In-Process Material	1008.2	5.7	994.2	6.8	929.0	5.4
3	I 1	Inspect - Form, Dimen.	145.8	0.8	154.5	1.1	149.8	0.9
4	I 2	Inspect - Weld, Bond	371.1	2.1	291.5	2.0	221.9	1.3
5	I 3	Inspect - Assem., Other	147.2	0.9	147.6	1.0	147.6	0.9
6	S 1	Machining	148.9	0.9	130.4	0.9	130.4	0.8
7	S 2	Forming	123.6	0.7	115.2	0.8	115.2	0.7
8	S 3	Joining	660.3	3.8	585.8	4.0	516.1	3.0
9	T 1	Tooling, Material, Handling	444.6	2.5	440.2	3.0	440.2	2.6
10	T 2	Jigs and Fixtures	355.0	2.0	412.0	2.8	312.0	1.8
11	A 1	Test - Accept	81.0	0.4	81.0	0.6	81.0	0.5
12	D 1	Storage	1.5	-	1.5	-	1.5	-
13	D 2	Transport	80.8	0.4	14.4	0.1	14.4	0.1
14	F 1	Facilities - Buildings	9384.0	53.4	6972.0	48.0	6972.0	40.7
15	F 2	Furnaces and Machine Tools	2998.5	17.1	2543.5	17.5	5443.5	31.7
16	P 1	Processing - Chem Mill, Anneal, Cure	97.5	0.6	165.5	1.1	159.6	0.9
17	L 1	Pre-Manufacturing Labor	1118.1	6.4	1118.1	7.7	1118.1	6.5
		Total	17576.1	100.0	14538.4	100.0	17132.3	100.0

Table 3-11

Distribution of Cost by Cost Group
For the Propellant Tank Structure (Element No. 2)
Rate = 20 per Year, Program Length = 5 Years

Line →			State of the Art (Line 1)		Improved (Line 2)		Advanced (Line 3)	
Cost Group		Cost Group Title	Program Cost		Program Cost		Program Cost	
No.	Designation		K$	% of Total	K$	% of Total	K$	% of Total
1	M 1	Raw Material	4100.0	6.1	3710.0	6.2	3800.0	6.6
2	M 2	In-Process Material	10082.0	15.0	9941.0	16.5	9040.0	15.5
3	I 1	Inspect - Form, Dimen.	1458.0	2.2	1544.5	2.6	1446.5	2.5
4	I 2	Inspect - Weld, Bond	3711.0	5.5	2914.5	4.8	2188.5	3.8
5	I 3	Inspect - Assem., Other	1471.5	2.2	1476.0	2.5	1465.5	2.5
6	S 1	Machining	1489.5	2.2	1303.5	2.2	1213.5	2.1
7	S 2	Forming	1236.0	1.9	1152.0	1.9	1152.0	2.0
8	S 3	Joining	6603.0	7.8	5859.0	9.7	5086.5	8.8
9	T 1	Tooling, Material, Handling	2184.8	3.3	2172.0	3.6	2172.0	3.7
10	T 2	Jigs and Fixtures	1083.0	1.6	1020.0	1.7	1020.0	1.8
11	A 1	Test - Accept	810.0	1.2	810.0	1.3	810.0	1.4
12	D 1	Storage	15.0	-	15.0	-	15.0	-
13	D 2	Transport	639.3	0.9	144.0	0.2	123.0	0.2
14	F 1	Facilities - Buildings	22833.0	33.8	16680.0	27.7	16680.0	28.7
15	F 2	Furnaces and Machine Tools	6228.5	9.2	7317.5	12.2	7867.5	13.5
16	P 1	Processing - Chem Mill, Anneal, Cure	975.0	1.4	1656.0	2.8	1531.5	2.6
17	L 1	Pre-Manufacturing Labor	2468.1	3.7	2468.1	4.1	2468.1	4.3
		Total	67387.7	100.0	60183.1	100.0	58079.6	100.0

Table 3-12

Support Frustum Structure (Element No. 1) Cost Distribution

System Identification			Cost Distribution— Percent of Total Cost (Upper Number) Cost in K$ (Lower Number)							Total Non Recurring Cost (%)	Total Recurring Cost (%)
Manufacturing Line Identification	Annual Output	Total Cost (K$) 5 Year Program	Tooling	Facilities	Pre-Mfg Labor Non Recurring	Pre-Mfg Labor Recurring	Material and Consumables	Labor QC	Labor Mfg		
Line 1 State of the Art	2 Per Year (Run 1D)	10 Units 1094.04	12.3 135	56.7 620	13.3 145	4.5 50	10.3 112	0.4 5	2.5 28	82.3	17.7
	20 Per Year (Run 2D)	100 Units 2183.74	4.9 107	28.4 620	6.6 145	22.7 495	22.8 497	2.1 45	12.5 274	39.9	60.1
Line 2 Improved	2 Per Year (Run 3D)	10 Units 1164.98	18.8 219	53.2 620	12.5 145	4.2 50	9.7 113	0.4 5	1.2 14	84.5	15.5
	20 Per Year (Run 4D	100 Units 2112.79	9.5 200	29.3 620	6.9 145	23.4 495	23.9 505	2.0 42	5.0 105	45.7	54.3
Line 3 Advanced	2 Per Year (Run 5D)	10 Units 1261.10	30.2 382	49.2 620	11.5 145	3.9 50	4.4 55	0.2 3	0.6 7	90.9	9.1
	20 Per Year (Run 6D)	100 Units 1974.67	19.3 382	31.4 620	7.3 145	25.1 495	12.0 236	1.3 27	3.6 70	68.8	31.2

Table 3-13

Propellant Tank Structure (Element 2) Cost Distribution

System Identification			Cost Distribution— Percent of Total Cost (Upper Number) Cost in K$ (Lower Number)								Total Recurring Costs (%)	Total Non Recurring Costs (%)
Manufacturing Line Identification	Annual Output	Total Cost (K$) 5 Year Program	Tooling	Facilities	Transport Plant #1 to Plant #2	Pre-Mfg Labor		Material and Consumables	Labor			
						Non Recurring	Recurring		QC	Mfg		
Line 1 State of the Art	2 Per Year	10 Tanks 17576.1 (Run 7D)	21.6 3798	53.4 9384	0.3 63	5.5 968	0.9 150	8.1 1418	3.8 664	6.4 1130	19.2	80.8
	20 Per Year	100 Tanks 67387.7 (Run 8D)	14.1 9496	33.9 22833	0.7 462	1.4 968	2.2 1500	21.0 14182	9.9 6640	16.8 11305	49.9	50.1
	* 20 Per Year	100 Tanks 54290.5 (Run 167)	17.5 9496	42.1 22833	0.8 462	1.8 968	0.9 490	26.1 14182	4.0 2168	6.8 3691	37.8	62.2
Line 2 Improved	2 Per Year	10 Tanks 14538.4 (Run 9D)	23.3 3396	48.0 6972	Not Applicable—Consolidated Plant No. 1 and Plant No. 2 Into a Single Unit	6.7 968	1.0 150	9.4 1370	4.1 589	7.5 1094	22.0	78.0
	20 Per Year	100 Tanks 60183.1 (Run 10D)	17.4 10509	27.7 16680		1.6 968	2.5 1500	22.8 13697	9.8 5889	18.2 10939	53.3	46.7
	* 20 Per Year	100 Tanks 47838.6 (Run 168)	21.9 10510	34.9 16680		2.0 968	1.0 490	28.6 13697	4.0 1923	7.5 3572	41.1	58.9
Line 3 Advanced	2 Per Year	10 Tanks 17132.3 (Run 11D)	36.2 6196	40.7 6972		5.7 968	0.9 150	7.6 1309	3.0 519	5.9 1018	17.4	82.6
	20 Per Year	100 Tanks 58079.6 (Run 12D)	19.0 11059	28.7 16680		1.7 968	2.6 1500	22.2 12863	8.7 5077	17.1 9931	50.6	47.4
	* 20 Per Year	100 Tanks 46960.5 (Run 169)	23.6 11060	35.5 16680		2.1 968	1.0 490	27.4 12863	3.5 1658	6.9 3242	38.8	61.2

* 80 Percent Learning Curve

3.4 RANKING AND OVERALL INTERACTION ANALYSES

3.4.1 IMPACT OF CHANGES ON PROGRAM COST

The effect of varying some of the parameters was studied so that the relative importance of the changes could be observed. Changes to the basic lines were evaluated for reasonable excursion of the selected parameters and are numbered 3 through 20 on Figure 3-7. The resultant change in cost for both elements is also shown on this figure. For this evaluation, these changes were selected to show the sensitivity of cost to the indicated parameter and are not necessarily practicable. Information related to these changes includes the following considerations:

Change 3—Relaxed tolerances by 100 percent, such as increasing an allowance of ± .002 to ± .004 for machining, illustrating the sensitivity of cost to design constraints and dimension tolerances.

Change 4—Reduced number of design changes by 20 percent illustrates the impact on cost if changes could be reduced below the 40-percent level of recycling assumed for these studies.

Change 5—Enlarges producibility files to include a 50-percent larger collection of data on processes and methods of fabrication, such as illustrated in the Appendices of Volume 3.

Change 6—Combine specifications issued separately by Engineering, Manufacturing and Quality Control groups for control of manufacturing. Typical specification processes are described in Section 2 of Volume 3.

Change 7—Improved scheduling of shop including 15 percent less changes of scheduling in the shop, with better control of shop loads.

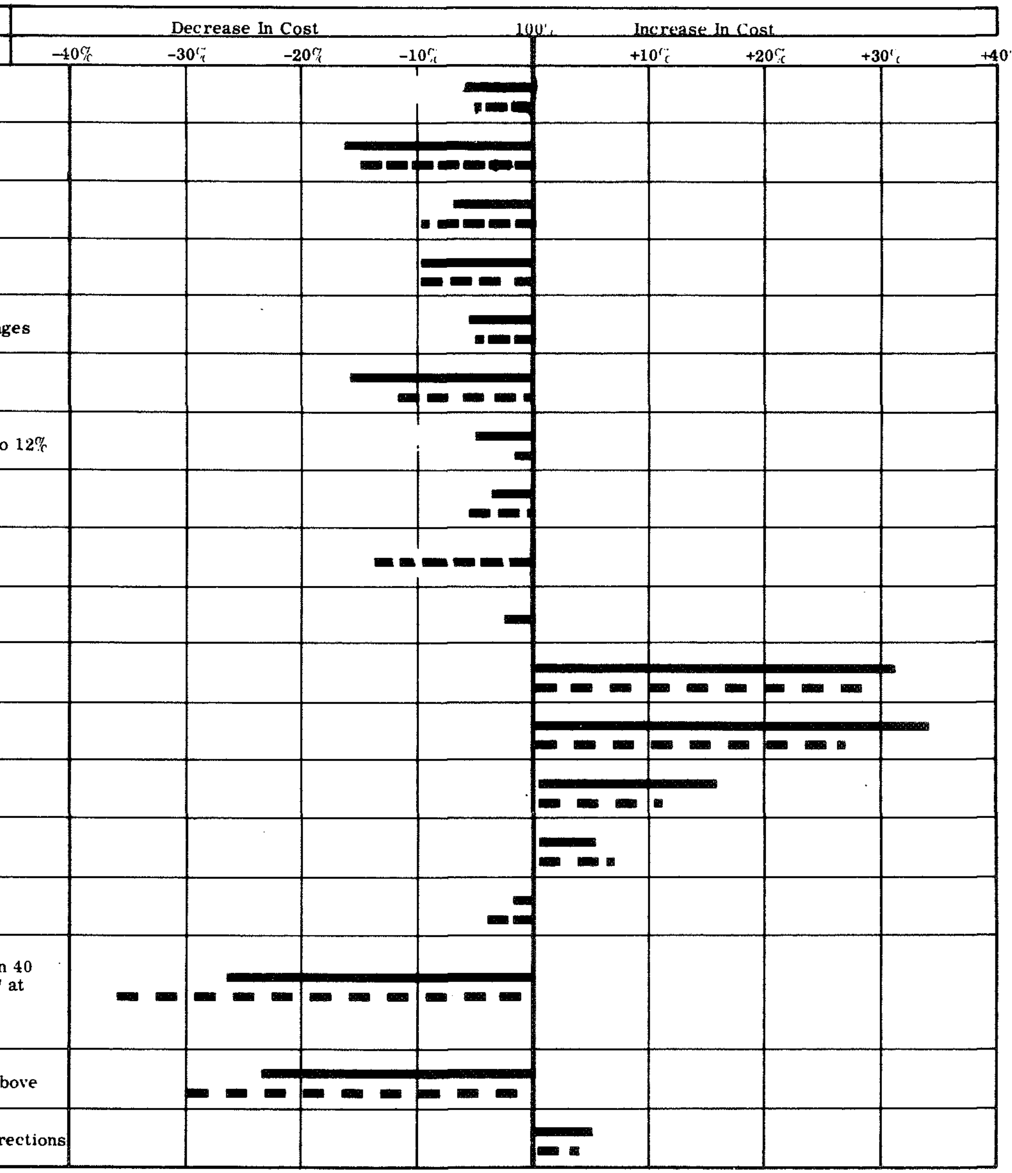
Change 8—Reduction of quality control process and labor cost, in particular the reduction of some redundant operation such as inspecting welds repeatedly by several methods, so that quality control operations are reduced 20 percent.

Change 9—Decrease of pre-manufacturing labor by reduction of recycle due to changes from 40 percent to 12 percent. This could result from reducing the number of changes going through the pre-manufacturing operations, with attendant cost savings shown in Figure 3-7.

Change 10—Reduce design complexity by simplifying design and hence manufacturing operations. The assumed measure is reduction of complexity and number of parts by 20 percent.

Change 11—Consolidate facilities (for element 2 only) from two plants into a single plant. This reduces costs of transportation, handling and the costs of maintaining separate facilities.

Change Identification	
Change No.	Change Description
3	Reduced Tolerances by 100%
4	Reduce No. of Design Changes by 20%
5	Enlarge Producibility Info File by 50%
6	Issue Joint Eng./Mfg./QC Specs
7	Improve Shop Schedules Load—15% Less Changes
8	Reduce Quality Required by 20%
9	Decrease Pre-Mfg. Labor Recycle From 40 to 12%
10	Reduce Design Complexity by 20%
11	Consolidate Facilities—One Factory—Line 1, Element 2 Only
12	Manned to Unmanned, Element 2 Only
13	Increase Product Size and Weight 20%
14	Train 50% of Work Force
15	Security—Nonclassified to Classified
16	Site Selection—Labor Cost Florida to Ohio
17	Delete Plant Safety
18	Depreciation—Straight Line (SL) F-1 to "O" in 40 Years, F2 to "O" in 14 Years, T1 to T2 to "O" at end of Program
19	Depreciation—Sum of Digits—Time Same as Above
20	Increase Shop Load 10% For Discrepancy Corrections



Percentages Shown are Based Upon Line 1—Production Rate 20/Year—Program Length 5 Years.

Element No. 1 ▬▬▬: Base Program Cost 2183.7 K$ (100 Elements, No Taxes or Interest)

Element No. 2 ▬ ▬ ▬ : Base Program Cost 67387.7 K$ (100 Elements, No Taxes or Interest)

Figure 3-7. Impact of Factor Changes on Manufacturing Costs

Change 12—Changes associated with changing a manned structure (man-rated) to an unmanned structure, but preserving the same design dimensional tolerances.

Change 13—Increase of element size and weight by 20 percent but keeping the same design configuration, materials and complexity.

Change 14—Includes those activities required to train 50 percent of the work force, such as might occur in a new location of the plant or fabricating structure in an environment where there was a 50-percent turnover in shop personnel.

Change 15—Impact of security classification (such as SECRET) on actual hardware costs. Costs reflect those changes which could be necessary if a manufactured item becomes classified.

Change 16—Changes and cost differences if the plants were located in Ohio rather than Florida.

Change 17—Changes in immediately identifiable costs if all such costs related to plant safety were eliminated. However, these costs do not include the resultant costs for lost-time accidents, reduced quality products or other losses which result from an inadequate safety program.

Change 18—Baseline costs assume facilities and tooling are written off 100 percent at the end of the program. This change indicates the cost savings noted if facilities and tooling have a value at the end of the program as noted in Figure 3-7, with straight line depreciation.

Change 19—Same as 18 but with value at the end of the program as determined by the sum of the year's digits.

Change 20—This change shows the cost increase associated with increased discrepancy and scrappage by 10 percent of nominal shop load.

The corresponding tabular values of the changes plotted in Figure 3-7 are given in Table 3-14.

Ranking these changes by impact on cost, the results are shown in Table 3-15 for both element 1 and element 2. As noted earlier, depreciation assumptions (and hence value of facilities at the end of the program) are important factors in determining manufacturing costs.

Table 3-14

Change Impact Study
State of the Art Manufacturing Line
(Based Upon Production Rate of 20 Elements/Year—5 Year Production Program—100 Elements)

Cost Item		Element No. 1			Element No. 2		
Change (Factor)		Program Cost-K$	Unit Cost K$	% Change	Program Cost-K$	Unit Cost K$	% Change
No.	Description Base	2183.7	21.8	0	67387.7	673.9	0
3	Relaxed Tolerances by 100%	2045.6	20.5	6.0	63519.0	635.2	- 5.8
4	Reduce No. of Design Changes by 20%	1818.7	18.2	-16.5	56913.8	569.1	-15.6
5	Enlarge Producibility Info. File by 50%	2024.2	20.2	- 7.3	60582.8	605.8	-10.1
6	Issue Joint Eng./Mfg./QC Specs	1972.8	19.7	- 9.6	60782.3	607.8	- 9.8
7	Improve Shop Schedule and Load—15% Less Changes	2057.4	20.6	- 5.5	63815.4	638.2	- 5.3
8	Reduce Quality Req. by 20%	1862.8	18.6	-14.2	59461.2	594.6	-11.7
9	Decrease Pre-Mfg. Labor Recycle from 40 to 12%	2055.7	20.6	- 5.5	66894.1	668.9	- 0.7
10	Reduce Design Complexity by 20%	2118.8	21.2	- 2.8	64301.2	643.0	- 4.6
11	Consolidate Facilities—One Factory	-	-	-	58640.5	586.4	-13.0
12	Manned to Unmanned	-	-	-	66249.4	662.5	- 1.7
13	Increase Product Size and Weight 20%	2853.7	28.5	+30.7	85952.8	859.5	+27.5
14	Train 50% of Work Force	2889.2	28.9	+32.6	83917.1	839.2	+24.5
15	Security—Unclassified to Classified	2532.1	25.3	+16.0	74748.5	747.5	+11.0
16	Site Selection—Labor Cost—Florida to Ohio	2307.7	23.1	+ 6.0	71954.3	719.5	+ 6.8
17	Delete Plant Safety	2162.4	21.6	- 0.9	65837.2	658.4	- 2.3
18	Depreciation—Straight Line F-1 to "0" in 40 Years F-2 to "0" in 14 Years T-1 to T-2 to "0" at End of Program	1604.5	16.1	-26.1	43536.7	435.4	-35.4
19	Depreciation—Sum of Digits	1679.6	16.8	-23.0	47128.0	471.3	-30.1
20	Increase Shop Load 10% for Discrepancy Corrections	2290.2	22.9	+ 5.0	69983.6	699.8	+ 3.8
10+13					81746.5	817.5	+21.2

Table 3-15

Relative Ranking of Selected Changes to the Basic Line*

Rank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Change Number	18	19	4	8	6	5	3	7	9	10	17	20	16	15	13	14			Element 1
Change Number	18	19	4	11	8	5	6	3	7	10	17	9	12	20	16	15	14	13	Element 2

*Basic Line is Line 1 for a Production Rate of 20 Per Year and a Five-Year Program (100 Units) with Full Depreciation at the End of Five Years.

3.4.2 SUMMARY OF OVERALL VARIATION IN MANUFACTURING COST

The overall impact of technology improvements on the manufacturing cost of the structural elements is shown by the change in costs from manufacturing line number 1 to manufacturing line number 3. This spans the total range considered in this study for impact of advancement in manufacturing technologies. For each element, both production capability rates (2 per year and 20 per year) were considered for two types of selected depreciation methods, e.g., 100 percent writeoff of tools and facilities at the end of the manufacturing program and straight line depreciation. Impact of taxes of 3 percent per year and interest on capital of 6 percent per year are also included in all of the results.

Figure 3-8 shows the results of this study. The results are presented so that the variation of the unit cost is given by the shaded range. For example, for Element Number 1, 2 per year production rate, and 100 percent depreciation method, Figure 3-8 shows that the total change in unit cost varies from a minimum of a 19-percent increase in cost to a maximum of a 26-percent increase in cost when going from the state-of-the-art manufacturing technology (line 1) to an advance manufacturing technology (line 3). The 26-percent increase in cost corresponds to a program which makes only one unit, and the 19-percent increase corresponds to a program in which 10 units are made. It should be noted that the bounds of this range change to 14 percent and 10 percent for the straight line depreciation method.

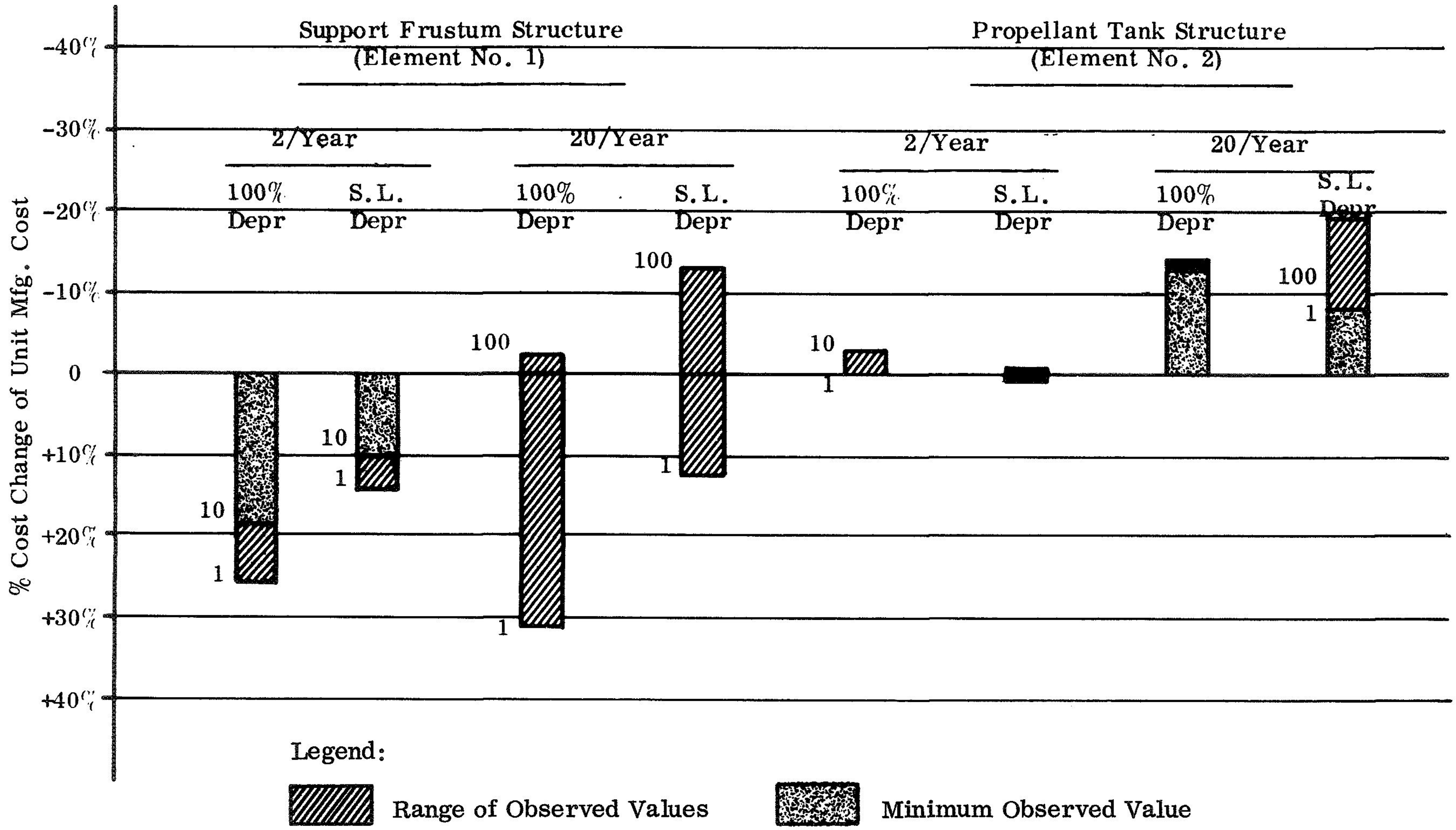


Figure 3-8. Ranges of Impact of Manufacturing Technology Improvement in Changing From Line Number 1 to Line Number 3.

The results in Figure 3-8 point out the fact that for Element Number 1, there is little cost advantage in going from the current line to an advanced technology as long as there is an interest in only low production rates. Also, the data shows that an insignificant advantage is gained by going to the advanced technology for Element Number 2 at the low production rate. It is only when the number of units produced is large (100) that a significant reduction in unit cost becomes evident. Other advantages, such as improved quality, reduced leakage potential, and higher reliability may accompany the manufacturing technology improvements

From the myriad of calculations made throughout this study the prime variables which affect the manufacturing cost of an element have been identified. These variables include the quantity produced, depreciation, taxes and interest, labor and material, and the learning effect. The range of impact which these variables have on manufacturing cost is given in Figure 3-9. The data presented in this figure are not meant to reflect the absolute upper and lower bounds; rather, these are the bounds determined from the selected cases for which calculations were made. The values are included to illustrate the sensitivity of costs to the major program variables and are not intended as practical suggestions for improvements. Bars are shown on the graph of Figure 3-9 for both 2 per year and 20 per year production rate capabilities for each of the categories and the program length is 5 years in all cases except those involving variation in quantity produced. It should be noted that the data includes both that of structural Element Number 1 and Element Number 2 and spans the technology differences of all three manufacturing lines.

Referring to Figure 3-9 it is observable that in increasing the quantity of units produced from 1 to 10 at the production capability of 2 per year the range of the cost reductions observed from all calculations was from 71 percent to 90 percent. For the 20 per year capability this range is from 92 percent to 99 percent which illustrates the potential of the higher production rates and quantity.

The range of cost reduction found when going from 100 percent depreciation to the straight line method is from 42 percent to 73 percent for the low production rate capability. This range is fairly large but again, the data covers cases involving both Elements Number 1 and Number 2 as well as spanning the technology advancements from the state-of-the-art line (line 1) to the advanced line (line 3). The labor and materials bars reemphasize one of the major results of this study, namely that for the low production capability the recurring labor costs are a small portion of total costs. They range from 9 percent to 25 percent for the cases chosen for investigation.

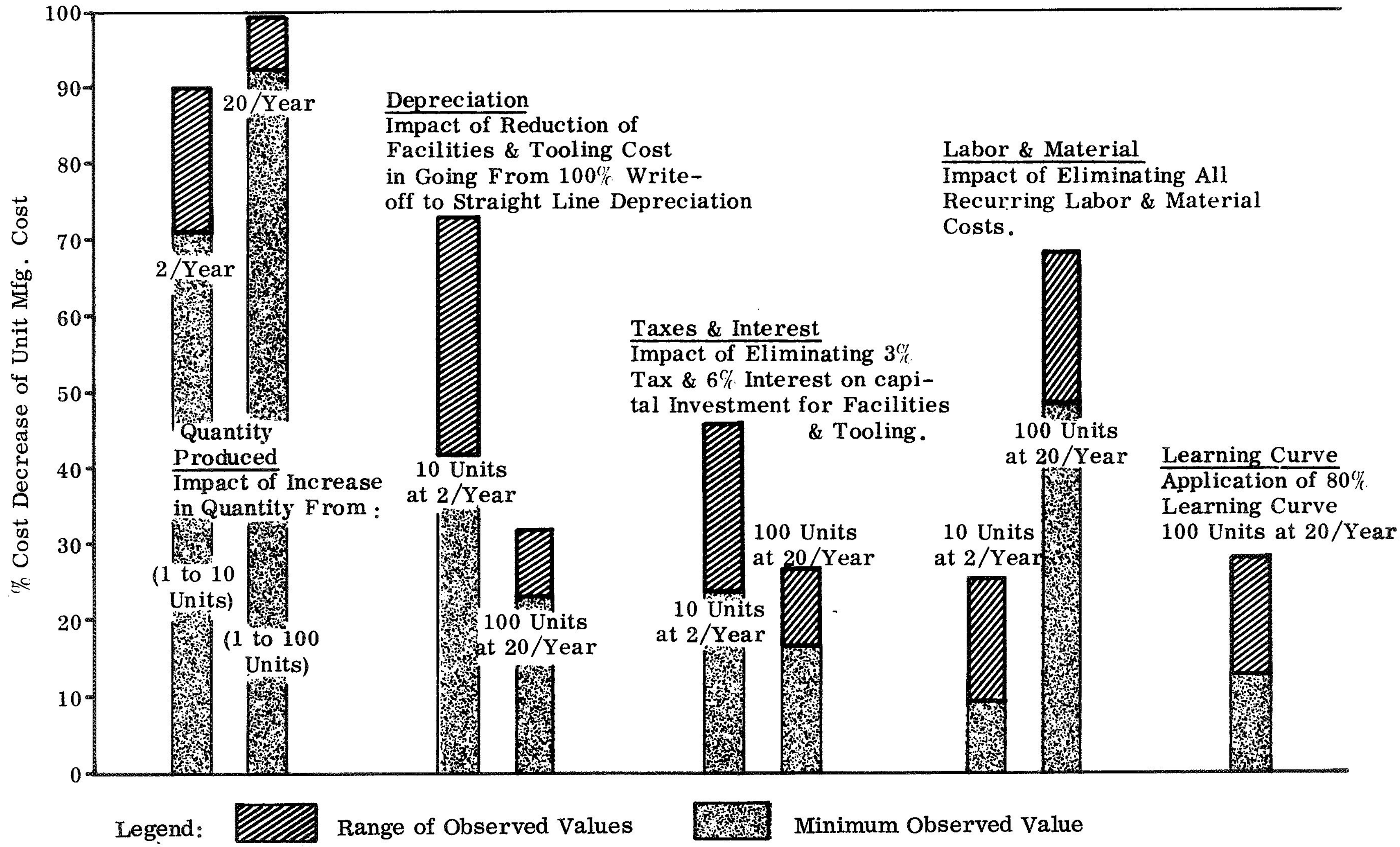


Figure 3-9. Ranges of Impact of Major Factors on Unit Manufacturing Costs

3.4.3 INTERACTIONS OF RESULTS

Results were evaluated for variations of several major factors simultaneously to study interaction effects. Figures 3-10 through 3-13 summarize results for both elements (one and two) and production capabilities (2 per year and 20 per year) showing unit production cost versus quantity for selected variations including:

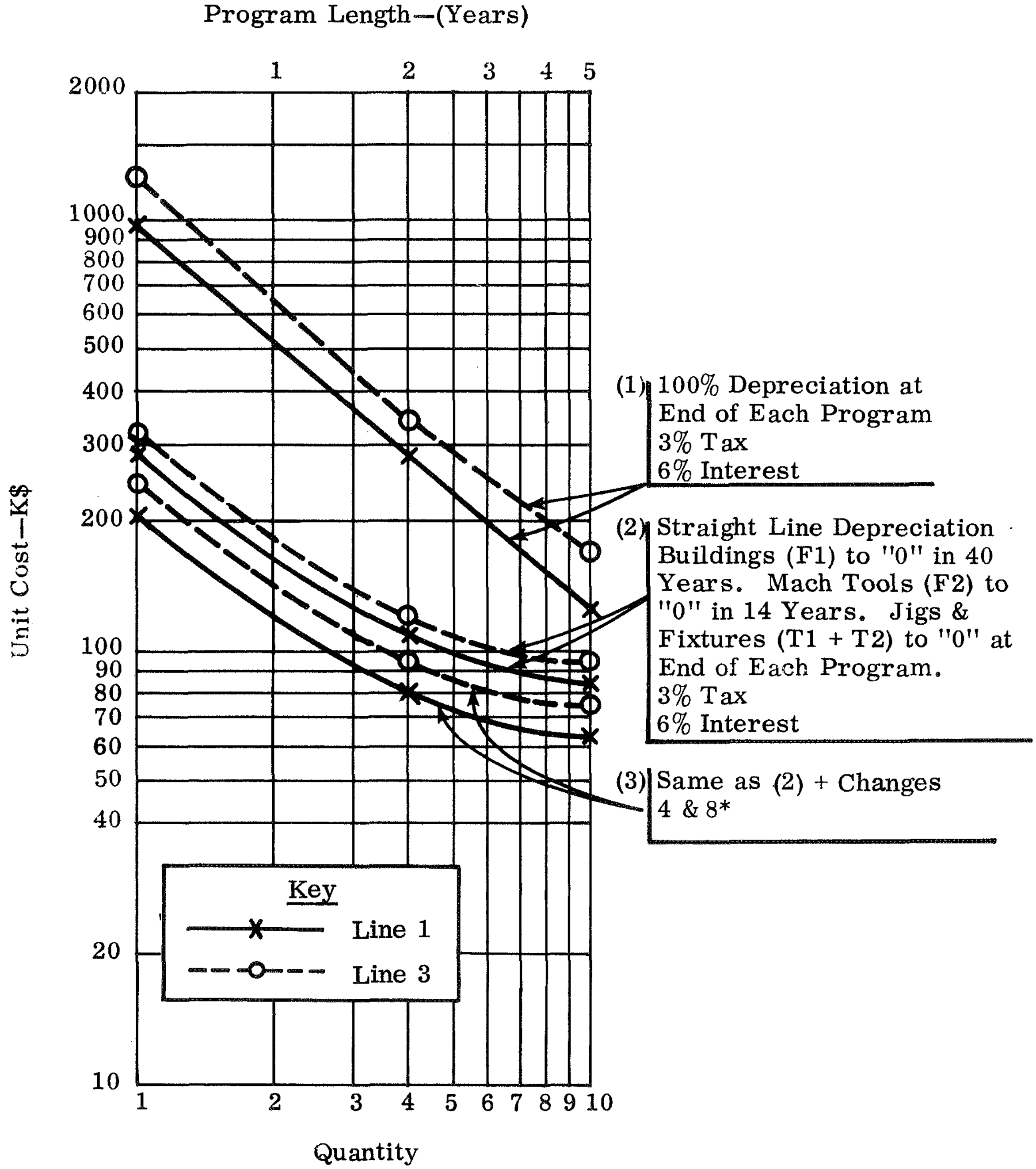
a. Program length.
b. Type of depreciation.
c. Inclusion of tax and interest.
d. Technology improvements from line number one to line number 3.
e. Selected factors (4, 5, 8) as listed in Table 3-1.
f. Learning Curve.

The strong impact of quantity, depreciation and factors are illustrated in these figures. For low quantity, the depreciation assumptions are important and the factors (e) and (f) above less important. As quantity increases, the per unit cost level drops and the impact of the other factors increases. Overall costs range over two orders of magnitude, indicating the importance of such manufacturing considerations.

The general approach used in the development of Figures 3-10 through 3-13 was to start with the conditions which give a realistic upper bound on cost which corresponds with the 100 percent depreciation including taxes and interest. From here a significant change was incorporated which tended to lower the cost; a change in the depreciation method, for instance. Then another change was included to lower the cost, proceeding finally to the condition considered to give a realistic lower bound on the cost. This approach included, of course, the parameters such as different lines, quantity, etc.

Figures 3-14 and 3-15 are a combination of some of the data presented in Figures 3-10 through 3-13. Figures 3-14 and 3-15 allow direct comparison of cost between the lower and higher production rates and the data encompasses the toal range of realistic costs from the upper to lower bounds.

The individual calculations including detailed discussions of interactions of some of the myriad of manufacturing factors are given in Section 6 of this report.



*See Figure 3-7 for Definition of Changes

Figure 3-10. Unit Cost Versus Quantity for Element No. 1 at a Production Rate of 2 per Year.

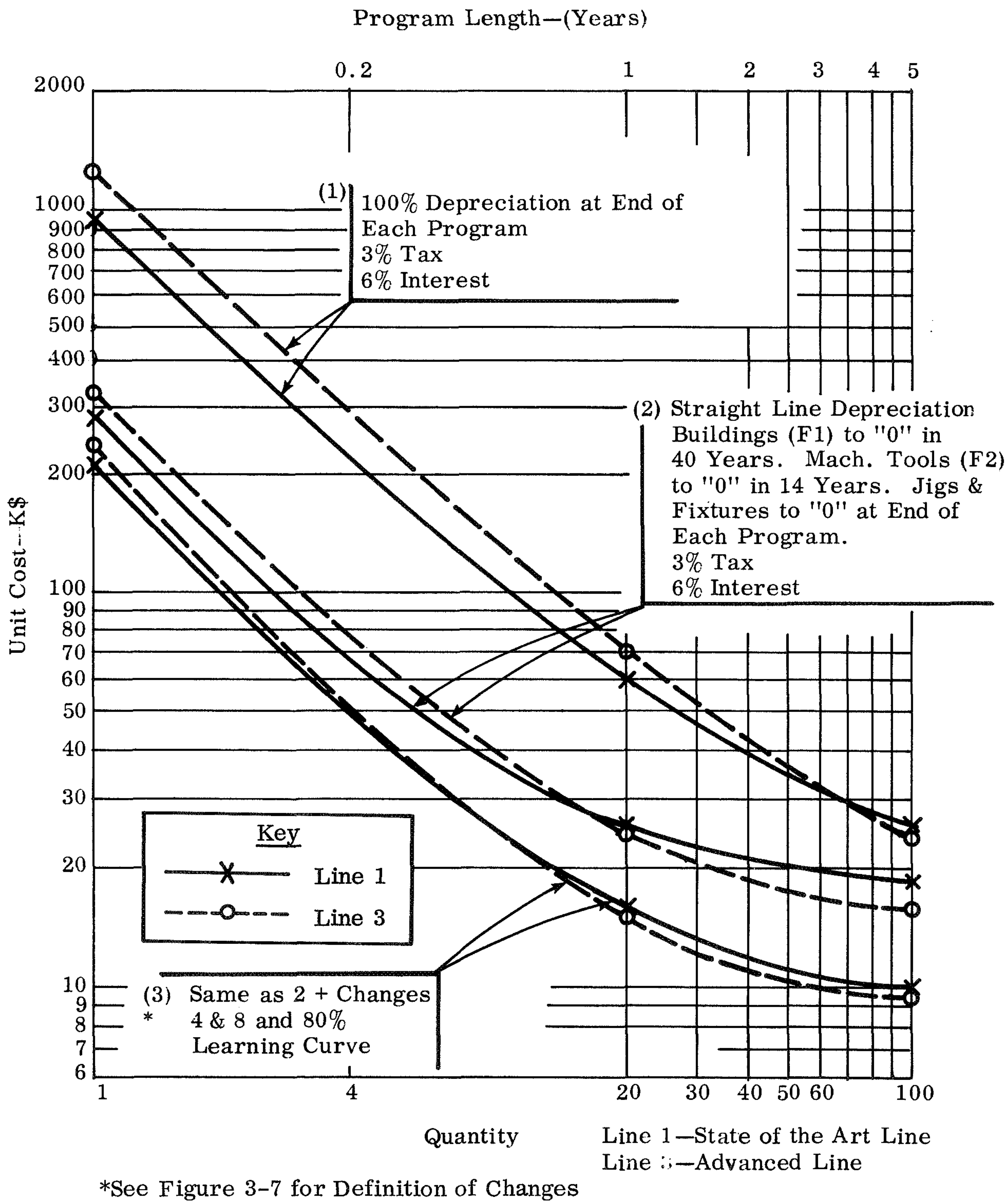
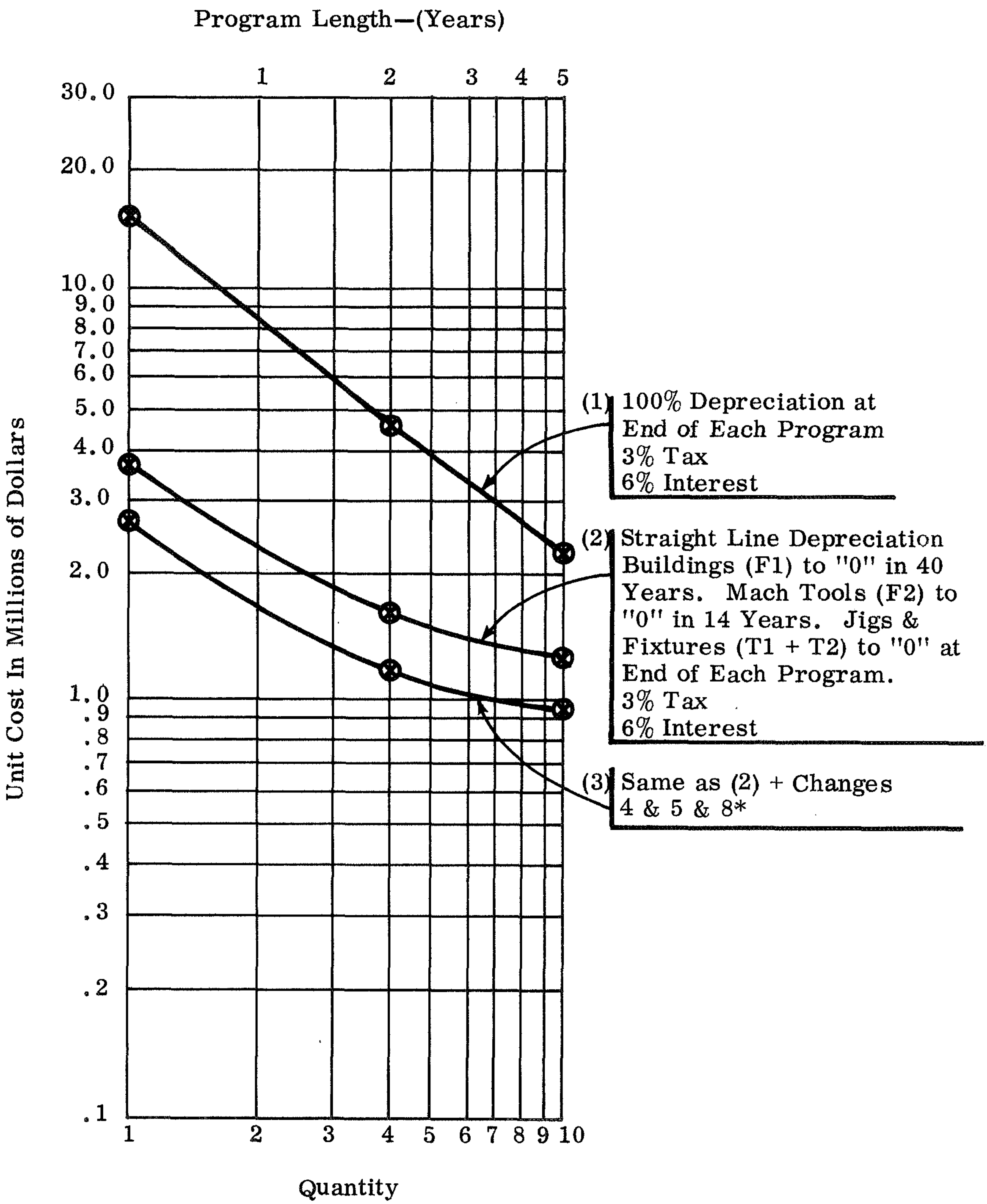
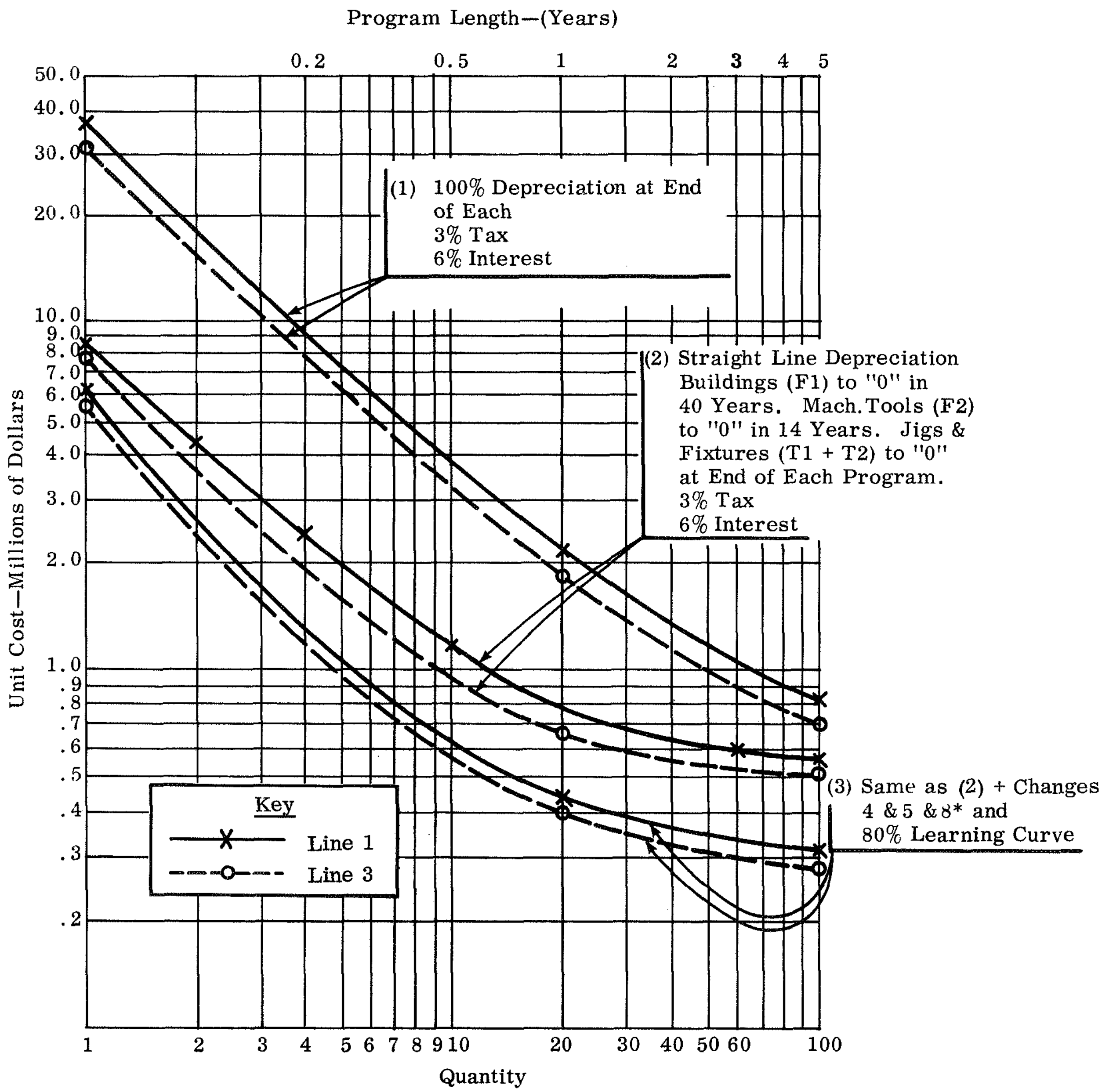


Figure 3-11. Unit Cost Versus Quantity for Element No. 1 at a Production Rate of 20 per Year



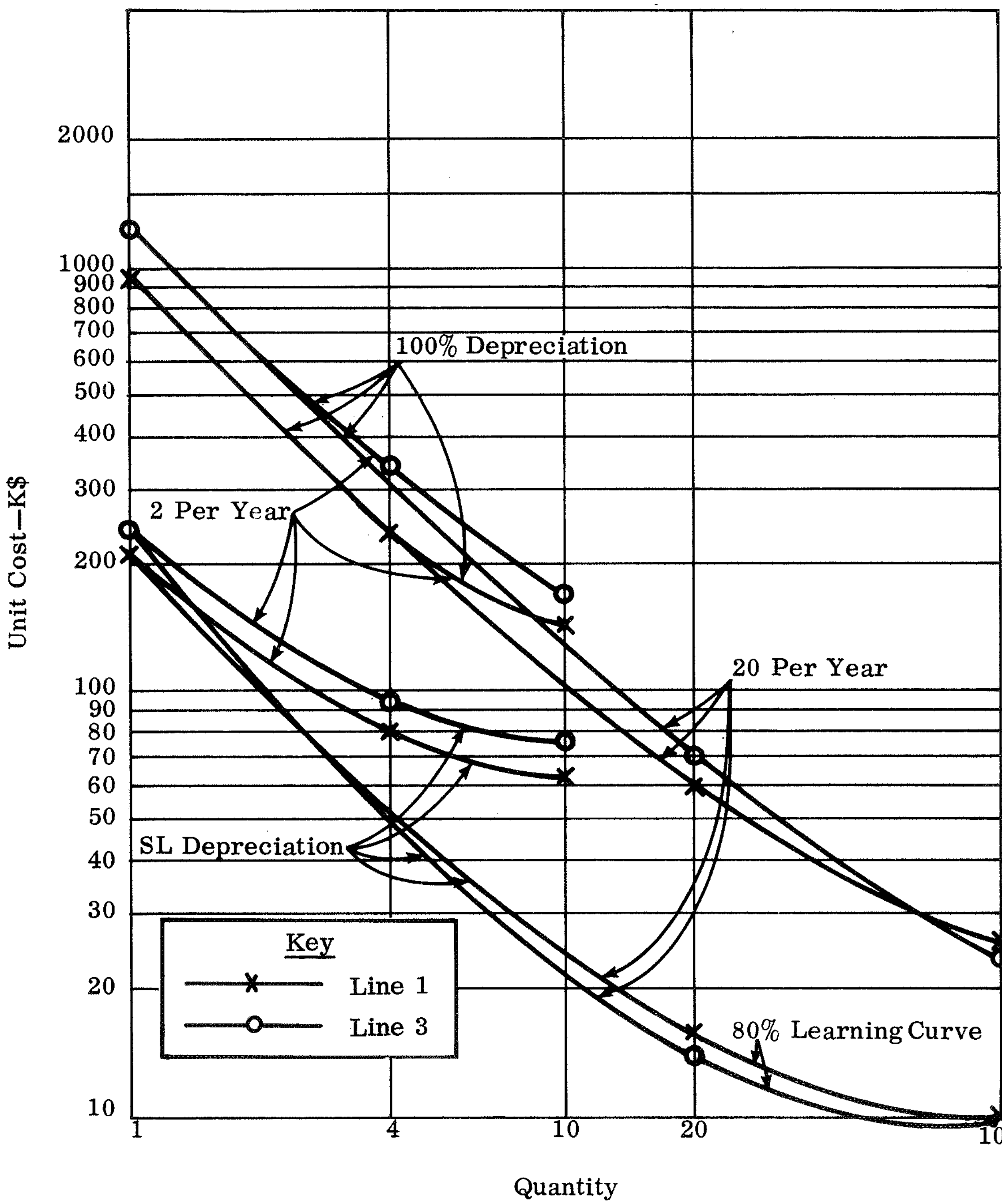
*See Figure 3-7 for Definition of Changes
Note—Line 1 and Line 3 Data Coincide for All 3 Cases in this Figure

Figure 3-12. Unit Cost Versus Quantity for Element No. 2 at a Production Rate of 2 per Year.



*See Figure 3-7 for Definition of Changes

Figure 3-13. Unit Cost Versus Quantity for Element No. 2 at a Production Rate of 20 per Year



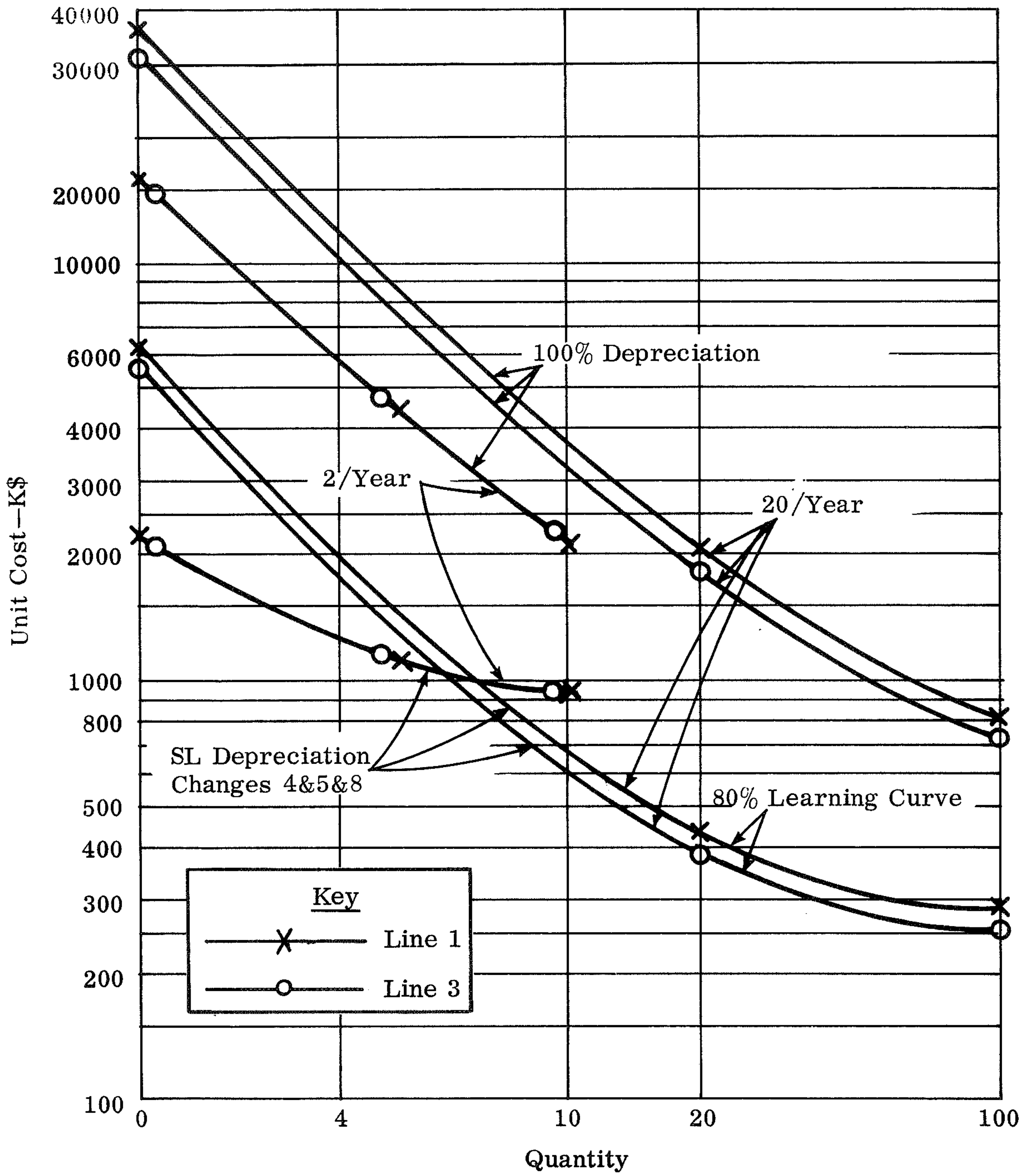
NOTES:

(1) 100% Learning Curve Except As Noted

(2) Changes 4 & 8 are Included in the Lower 4 Curves

(3) Tax and Interest Included—All Curves

Figure 3-14. Cost Impact of Quantity for Various Change for Element No. 1



NOTES:

(1) 100% Learning Curve except as noted.

(2) Changes 4&5&8 are included in the lower 3 curves.

(3) Tax and Interest included in all curves.

Figure 3-15. Cost Impact of Quantity for Various Changes for Element No. 2

3.5 CONCLUSIONS AND RECOMMENDATIONS

Quantity has the largest impact on the unit manufacturing cost of the typical aerospace structures considered in this study. Large nonrecurring costs (including facilities depreciation) are required which must be written off against a small number of units produced. As quantity increases, the nonrecurring cost burden for each unit decreases. Improved learning is the secondary contributor to reduced unit cost with increased quantity.

Other factors of significant influence are: (a) methods of joining pressurized structures, and (b) consolidation of facilities in which the manufacturing and assembly facilities are geographically separated. In the former case there is a potential for cost reduction through improved welding techniques. Improvements in this area may facilitate reduction in the extensive quality control labor required with present techniques. In the latter case, a significant cost reduction can be realized by consolidating the manufacturing and assembly facilities into a single plant.

The advanced manufacturing technologies investigated show limited potential for cost reduction for the conventional aluminum materials. Advancements in manufacturing have progressed at a pace consistent with related technologies leaving only limited potential for major cost reductions. However, significant benefits of manufacturing technology advancements may be realized through improvements in quality.

In general, large (order of magnitude) cost reductions are not indicated for the conventional materials and designs at the low quantities inherent with most aerospace structural applications. The most significant area for large cost reduction, within the constraints of limited quantity, is in the potential of advanced designs which minimize nonrecurring (facilities and tooling) costs. Advanced materials, such as composite materials, may be in this category. Advanced techniques for fabrication and inspection may permit low cost facilities and hence significant cost reductions for future aerospace equipment.

Recommendations for further studies to better define technology and explore cost reductions include the following:

a. Advanced materials study to explore potential for reduced nonrecurring costs as well as improved quality and performance.
b. Evaluation of applicability of these study results to aircraft and to reusable space vehicle structures.

c. Low cost facilities study.

d. Welding techniques and quality control study.

e. Use of the "MANCAN" computer program for other manufacturing applications including analysis and documentation of processes.

These studies, particularly a. and b. above, should lead to identification and exploration of new fields of technology for future lower-cost vehicles.

SECTION 4

MANUFACTURING COMPUTER MODEL

4.1 METHODOLOGY

4.1.1 MODEL REQUIREMENTS

Requirements were established for a manufacturing computer model as follows:

a. Definition—A semi-automated (combined manual and computer routines) model shall be capable of rapidly assembling costs and labor distributions for each of the detailed steps in the manufacturing process.

b. Objective—This model shall have the capability to rapidly evaluate influence of variable program factors and manufacturing technology on cost and worth.

c. Scope—The model shall include facilities and grounds, tooling, machine tools, jigs and fixtures, pre-manufacturing (expediting), quality control, manufacturing processes, and manufacturing test. The model shall encompass sufficient flexibility to handle various structural configurations, line configurations, rates of production and period of production (total quantity), and plant locations.

d. Learning Curve—The model shall include provisions for incorporating reduction in cost as a function of quantity produced, by a standard learning curve procedure (such as the Stanford Learning Curve).

e. Operation—The automated system shall be set up in a user-interactive mode on a time-sharing computer system so that the user can control runs and output from a remote terminal. Instructions may be entered either directly or from a storage file.

f. Output—The program shall produce either a detailed or summary output listing each of the categories of cost and labor activity and the subtotals by each of these categories. The output shall indicate assumptions as well as results. Costs and labor shall be expressed either in absolute numbers or as percent of the totals.

A schematic illustration of the model requirements is shown in Figure 4-1. In this figure, those operations external to the computer program are noted, as well as inputs and outputs to each module or operation. The basic computer program is shown in

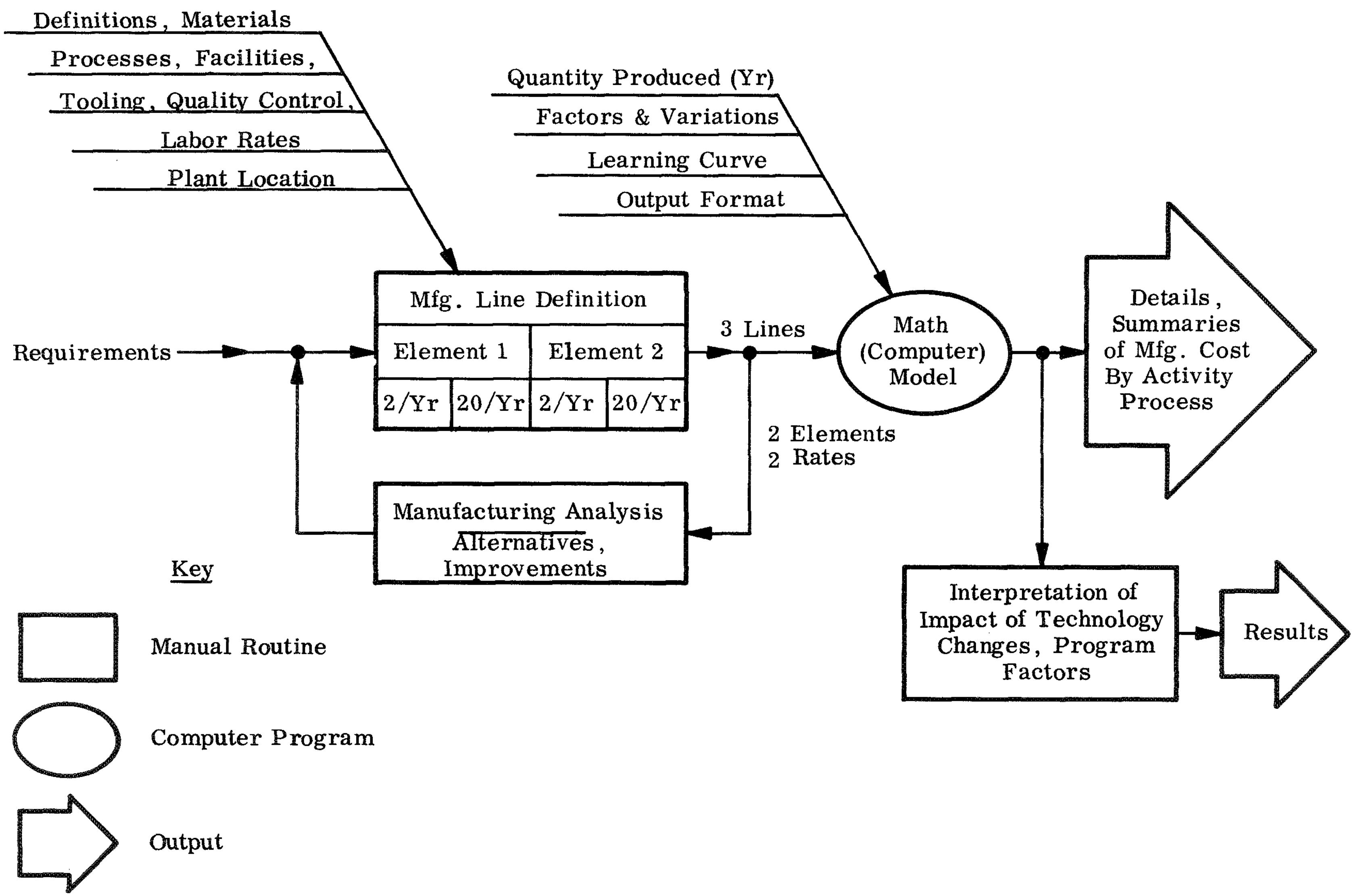


Figure 4-1. Manufacturing Model

the elliptical frame; the other activities support or analyze results of this basic program. The manufacturing line definition was performed manually, and the resultant lines and analyses are described in Section 5.

4.1.2 MODEL SELECTION

In selecting a model to meet the above requirements, several possible types of models were considered, including:

a. Explicit model—building each model as required to meet specific requirements of each line. This would result in as many models as combinations of lines and configurations.
b. Simulation model which simulates the flow process by simulating each step, process utilization of machines, personnel, etc. An example of this simulation is the GPSS program such as described in Reference 12. Again, a separate model is required for each line.
c. Simplistic (throughput) model, which accumulates costs from specific data files in a general purpose assembly program with a specific output format.

The third model type above—the simplistic or throughput model—was selected to more readily accommodate the study data while producing outputs on a standardized format. This model, described in more detail in the following paragraph, is an accumulation type of system where data is identified and summed to produce requested totals. No simulation or looping features are provided, rather each individual step is determined and costed separately on a one-time-through basis. This simplicity allows considerable flexibility in the data processed and virtually unlimited number of input line configuration and factors studies.

With the selected model, the input data and line identification items are processed manually into data files prior to operation of the computer program. In like manner the interpretation of the impact of technology improvements or variations in program factors are performed manually using several assisting programs as desired from the time-sharing libraries, including:

a. Regression analysis to determine impact of multiple variables on results.
b. Integer programming optimization routines to select preferred combinations of improvements in the presence of real program constraints.
c. Factorial design analysis.

The results are interpreted and assembled in Section 6 to indicate impact of program parameters on total costs.

4.2 MANUFACTURING COMPUTER MODEL DESCRIPTION

4.2.1 SUMMARY

In summary, the automated manufacturing model is a system that quantifies the cost of manufacturing a typical piece of aerospace structure. The manufacture of specified structures is considered in detail. The costs incurred are broken down into four categories:

a. Tooling.
b. Facilities.
c. Pre-Manufacturing.
d. Manufacturing Processes.

The individual steps that are performed during the manufacture of these structures are input together with manufacturing labor rates and other data into separate files. The basic set of steps that are performed to manufacture these structures based on current technology and capabilities are denoted as the state-of-the-art manufacturing line (Line 1). The costs associated with the total manufacturing activity for a structure are accumulated and displayed as total cost.

In addition to the basic manufacturing line (Line 1), two additional manufacturing lines are established (Lines 2 and 3): Line 2 incorporates improvements that can be made to Line 1 with present technology and Line 3 incorporates advanced manufacturing ideas that are determined to be feasible for the manufacture of these types of structures.

Options available include the capability of varying production rate (2 per year and 20 per year), quantity produced, and use of learning curves. The capability has been included to allow assessment of the difference in total program costs when specific changes are made in the nominal manufacturing procedures.

4.2.2 INPUT/OUTPUT

The input requirements and the output options of the Manufacturing Cost Analysis Program (MANCAN) are shown in Figure 4-2.

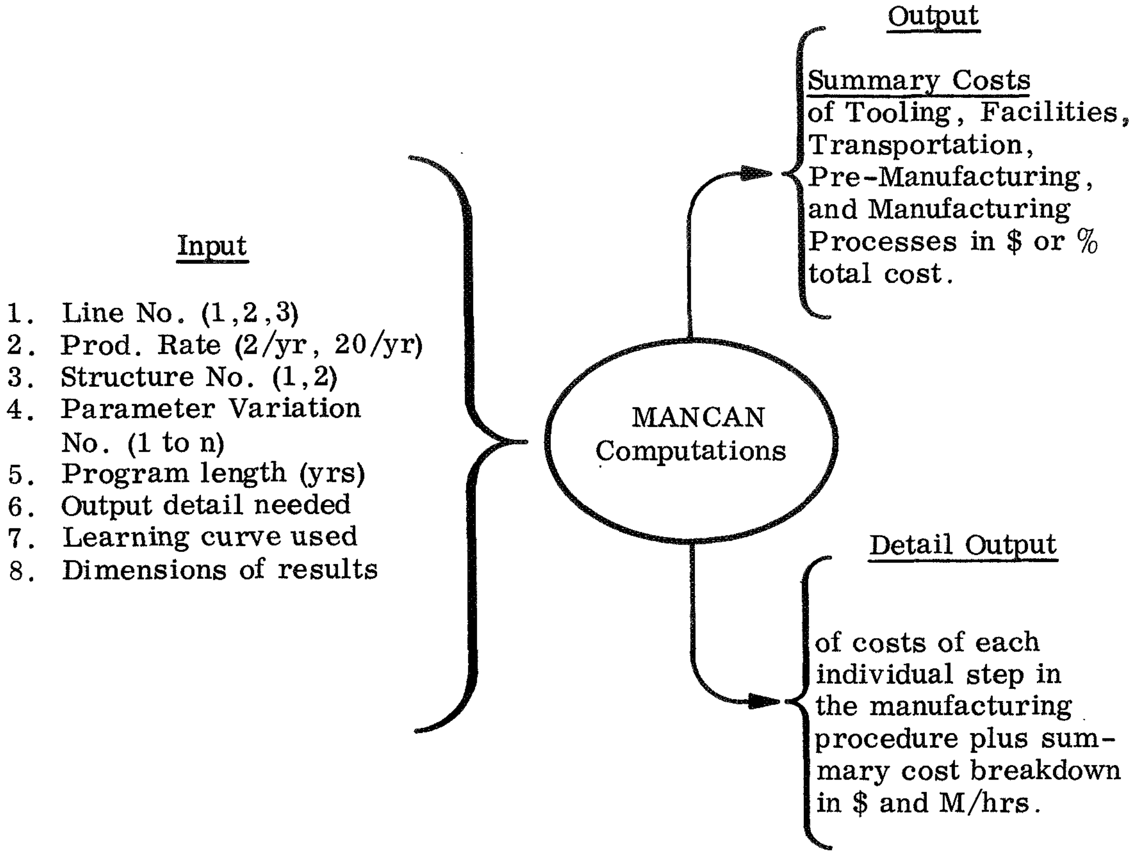


Figure 4-2. Input/Output of the Manufacturing Cost Analysis Program (MANCAN)

4.2.3 MATH MODEL

Typical equations for cost calculations include the following:

Let

K5 = Program Length (Years).

K6 = Production Rate.

L5 = Quality Control Labor Rate.

L6 = Manufacturing Labor Rate.

F = Learning Curve Factor.

K4 = Change Number.

$D_{i,j}$ = The matrix containing material cost, quality control labor and manufacturing labor cost data.

$d_{i,j}$ = Elements of $D_{i,j}$

$d_{i,1}$ = Material cost per unit.

$d_{i,2}$ = Material correction factor code number.

$d_{i,3}$ = Quality Control labor (M/hrs) per unit.

$d_{i,4}$ = Quality Control labor correction factor code number.

$d_{i,5}$ = Manufacturing Labor (M/hrs) per unit.

$d_{i,6}$ = Manufacturing Labor correction factor code number.

$C_{i,j}$ = Matrix of correction factors.

$c_{i,j}$ = Element of matrix $C_{i,j}$. (Correction factor j corresponding to change i from the nominal case.)

N = Total number of steps in Manufacturing Process.

T1 = Material cost.

T2 = Quality Control labor cost.

T3 = Manufacturing labor cost.

i = Manufacturing step number.

Then

$$T1_i = (K5)\ (K6)\ (d_{i,1})\ (c_{K4,\ d_{i,2}})$$

$$T2_i = (K5)\ (K6)\ (F)\ (d_{i,3})\ (c_{K4,\ d_{i,4}})\ (L5)$$

$$T3_i = (K5)\ (K6)\ (F)\ (d_{i,5})\ (c_{K4,\ d_{i,6}})\ (L6)$$

where

$$F = \begin{cases} 1 , & K6 = 2 \\ \dfrac{1}{20\ (K5)} \displaystyle\sum_{I=1}^{20\ (K5)} (I)^S , & K6 = 20 \end{cases}$$

S = Slope of learning curve on log-log paper.

The total process cost is therefore

$$T = \sum_{i=1}^{N} (T1_i + T2_i + T3_i).$$

The material cost, quality control labor and manufacturing labor costs are, respectively:

$$T1 = \sum_{i=1}^{N} T1_i$$

$$T2 = \sum_{i=1}^{N} T2_i$$

$$T3 = \sum_{i=1}^{N} T3_i$$

4.2.4 FLOW DIAGRAM

A flow diagram for the manufacturing line computer program MANCAN is shown in Figure 4-3. The files with supporting data which can be called to run this program are shown in Table 4-1. The main program is called MANCAN, the file containing factor variation with program change is named FACTORS.

The main data files are listed in the matrix in Table 4-2, with file titles indicated at appropriate locations on this matrix.

Table 4-1

MANCAN Operating Files

Name	Title
Factors	FACTORS
Main Program	MANCAN
Input Data	INPUT

4.2.5 EXAMPLE OF OPERATION

A sample operation is shown in Figure 4-4, which gives the steps necessary to run the MANCAN program. All of the circled information was typed in by the program operator.

Table 4-2

MANCAN Files
(Words in Matrix Indicate Names of Files Called During the Operation of MANCAN)

Type of Data		Element No. 2						Element No. 1					
		Line 1		Line 2		Line 3		Line 1		Line 2		Line 3	
		2 Per Year	20 Per Year	2 Per Year	20 Per Year	2 Per Year	20 Per Year	2 Per Year	20 Per Year	2 Per Year	20 Per Year	2 Per Year	20 Per Year
Tooling	Description File	LINE1	LINE1	LINE2	LINE2	LINE3	LINE3	LINE4	LINE4	LINE5	LINE5	LINE6	LINE6
	Data File	DATA1	DATA1	DATA2	DATA2	DATA3	DATA3	DATA4	DATA4	DATA5	DATA5	DATA6	DATA6
Facility and Transp.	Data File	FACIL1		FACIL2				FACIL3					
Pre-Mfg.	Description File	L1PREM											
	Data File	D1PREM											
Mfg.	Description File	LINE1P		LINE2P			LIN3AP	LINE4P	LIN4AP	LINE5P	LIN5AP	LINE6P	
	Data File	DATA1P		DATA2P		DATA3P	DAT3AP	DATA4P	DAT4AP	DATA5P	DAT5AP	DATA6P	DAT6AP

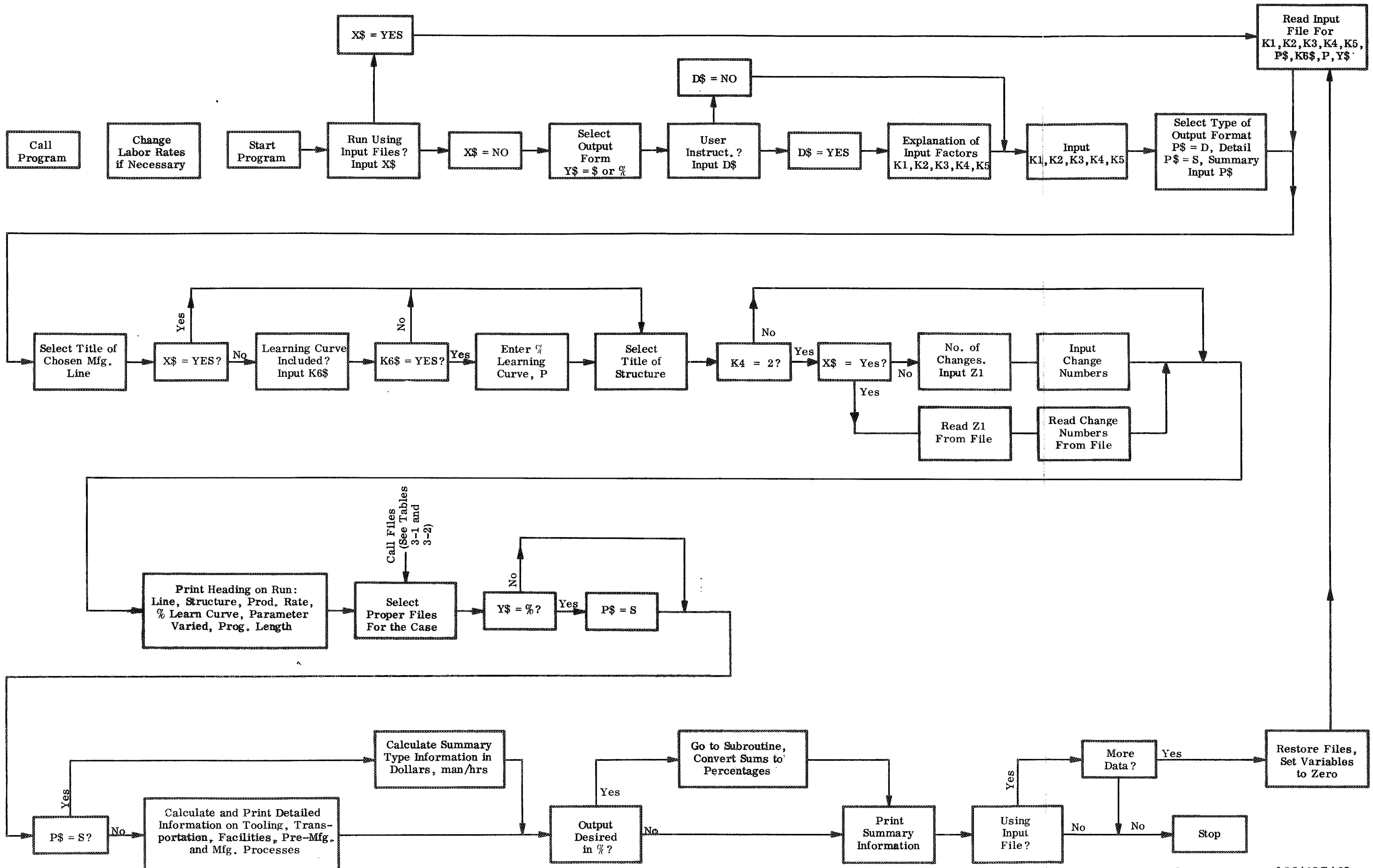


Figure 4-3. Flow Diagram of MANCAN Program

```
MARK II   G-529   10:21 EST   24 DEC 70
USER NO.--GPW01601,
PROJECT ID--AMES
SYSTEM--BASIC
NEW OR OLD--OLD
ENTER FILE NAME-MANCAN
READY
RUN


MANCAN        10:22 G     12/24/70

DO YOU WANT TO RUN USING FILE INPUT? TYPE YES OR NO.?NO
DO YOU WANT THE OUTPUT IN '$' OR '% OF TOTAL COST'?TYPE $ OR %.?$
DO YOU DESIRE USER INSTRUCTIONS? TYPE YES OR NO.?YES
     THERE ARE FIVE FACTORS WHICH MUST BE INPUT WHEN THE
NEXT QUESTION MARK APPEARS.  THESE MUST BE INPUT IN THE
FOLLOWING ORDER:  K1,K2,K3,K4,K5
WHERE:

   K1= LINE NUMBER (1,2,OR 3)
     K1=1: STATE-OF-THE-ART MANUFACTURING LINE
     K1=2: IMPROVED MANUFACTURING LINE
     K1=3: ADVANCED MANUFACTURING LINE
   K2 ALLOWS THE PRODUCTION RATE SELECTION
     (K2=1 FOR 2/YR, K2=2 FOR 20/YR)
   K3 ALLOWS THE SELECTION OF THE STRUCTURE
     K3=1 FOR THE TANK ASSEMBLY
     K3=2 FOR THE MARK XII ADAPTER ASSEMBLY
   K4 ALLOWS THE SELECTION OF A CHANGE TO BE MADE TO THE NOMINAL
   MANUFACTURING LINE
     K4=1: FOR THE NOMINAL LINE
     K4=2: ANY COMBINATION OF THE FOLLOWING CHANGES
     K4=3: TOLERANCES ARE RELAXED BY 100%
     K4=4: DESIGN CHANGES REDUCED BY 20%
     K4=5: PRODUCIBILITY FILE ENLARGED BY 50%
     K4=6: ISSUE JOINT ENGR/MFG/QC SPECS
     K4=7: IMPROVED SHOP SCHEDULE & LOAD
     K4=8: REDUCE QUALITY REQ'MTS BY 20%
     K4=9: DECREASE PRE-MFG. LABOR RECYCLE TO 12%
        NOTE: 40% LABOR RECYCLE CONSIDERED NOMINAL
     K4=10: REDUCE DESIGN COMPLEXITY BY 20%
     K4=11: CONSOLIDATE TO 1 FACILITY
     K4=12: GO FROM MANNED TO UNMANNED
     K4=13: INCREASE PRODUCT SIZE & WT. BY 20%
     K4=14: TRAIN 50% OF WORK FORCE
     K4=15: GO FROM UNCLASS. TO CLASSIFIED SECURITY
     K4=16: MOVE MFG. PLANT FROM FLA. TO OHIO
     K4=17: DELETE PLANT SAFETY PROGRAM
     K4=18: 5 YR ST. LINE DEPRECIATION
     K4=19: SUM OF YRS DIGIT DEPREC.
     K4=20: INCR. SHOP LOAD 10% FOR CORRECTIONS
   K5 IS THE TOTAL PROGRAM LENGTH IN YEARS
?1,2,1,2,5
DO YOU WANT DETAILED OUTPUT(ENTER D),OR SUMMARY(ENTER S)?S
DO YOU WANT A LEARNING CURVE EFFECT INCLUDED? YES OR NO? YES
ENTER THE PERCENT STANFORD CURVE DESIRED ?80
ENTER THE TOTAL NO. OF CHANGES?3
ENTER THE 3 CHANGE NUMBERS?4,5,8
```

Figure 4-4. MANCAN Program Operation

After the READY signal is received, the program is available to the operator. If any changes are necessary, they can be made at this time. For example, the hourly labor rate for Quality Control, Manufacturing, and Pre-Manufacturing activities has been assumed to be $15 per hour for most of the cases investigated. These rates can be changed by changing lines 140, 150, and 160 of the program. This can be seen by inspecting these line numbers in the program listing in Appendix A.

Following the changes to the program, the program can be started by typing RUN. The first question that must be answered is whether or not to make a run using the INPUT file. The INPUT file is a file that is created external to the main program MANCAN. If a number of runs is to be made, this is the method whereby all of the runs can be made at one time by establishing a file called INPUT. Each line of the INPUT file must have at least nine entries; these entries correspond to the nine variables K1, K2, K3, K4, K5, P$, K6$, P, Y$, Z1, Z(1), Z(2) . . . Z(Z1). The first five variables are defined by the information in Figure 4-4. P$ is the key that allows the selection of the output printout format; input S for Summary, D for detailed or B for both. K6$ is either YES or NO and answers the question as to whether a learning curve is to be included. P is the percent learning curve desired if used, and Y$ is either $ or %, which tells the program whether the results are to be printed in dollars or in percent of total program cost. If more than one change is to be incorporated in a run K4 must = 2, and the Z factors following Y$ must be put in. Z1 gives the total number of changes to be incorporated simultaneously and the Z(i) are the actual change numbers to be incorporated. It should be noted that the combination of changes to be used simultaneously should be chosen discretely. For instance the results would have little meaning if two types of depreciation were considered at the same time. The program logic will allow any of the changes to be used simultaneously so it is left to the user to be aware of what he is asking.

Each line of nine (or more) entries in the INPUT file establishes the data necessary for one run of the program, and as many cases as desired can be put in the file. If the INPUT file is not used, the program proceeds to ask questions as shown in Figure 4-4 so that enough data is obtained to make a run.

The computer output corresponding to the data given in Figure 4-4 is shown in Figure 4-5.

MANUFACTURING COST ANALYSIS
****

LINE: STATE-OF-THE-ART MANUFACTURING LINE (LINE 1)

STRUCTURE: PROPELLANT TANK STRUCTURE (ELEMENT 2)

PRODUCTION RATE: 20 PER YEAR

PERCENT LEARNING CURVE USED: 80

VARIATION FROM THE NOMINAL: CHANGE NO.(S) 4 + 5 + 8

TOTAL PROGRAM LENGTH: 5 YEARS; NO. OF UNITS PRODUCED: 100

LABOR RATES-($/HR): PRE-MFG.- 15. ; Q.C.- 15. ; MFG.- 15.

SUMMARY OF RESULTS

	MAT'L COST (K$)	Q.C. LABOR (M/HR)	MFG. LABOR (M/HR)	PRE-MFG. LABOR (M/HR)	TOTAL COST (K$)
TOOLING					7241.95
FACILITIES					18494.7
TRANSPORTATION					
NON-RECURRING COST					46.8504
RECURRING COST					252.72
PRE-MANUFACTURING					
NON-RECURRING COST				41305.6	619.584
RECURRING COST				20895.	313.425
MFG. PROCESSES	7147.73	72845.5	159789.		10636.1
	7147.73	72845.5	159789.	62200.6	37605.3

LABOR IN (K$) (1092.68) (2395.64) UNIT COST: 376.053

USED 5.55 UNITS

Figure 4-5. MANCAN Output Corresponding to Input Given in Figure 4-4.

SECTION 5

IDENTIFICATION OF MANUFACTURING LINES AND POTENTIAL AREAS FOR IMPROVEMENT

5.1 DESCRIPTION, STATE OF THE ART MANUFACTURING LINE, LINE 1

5.1.1 PROPELLANT TANK STRUCTURE, ELEMENT NO. 2

5.1.1.1 General Description

The liquid hydrogen, liquid oxygen propellant tank structure, illustrated in Figure 2-2, is characteristic of large tanks used on the Saturn V and planned for the Space Shuttle. For this study, the aluminum alloys are retained with at least some welding on all designs. Since the structure must be absolutely pressure tight—especially between the hydrogen and oxygen tanks, considerable care and inspection are required. This requirement, coupled with the large (260-inch diameter) size has necessitated a rather detailed manufacturing analysis. However, this structure should provide realistic observations and study results of the impact of program factors on construction, since its size and construction are similar to today's technology. The construction of this tank is a hybrid between the methods used on the S-II stage, S-IVB stage, or planned for use on the Space Shuttle tankage. The manufacturing lines are principally concerned with two domes, a common bulkhead, and a cylindrical section. Characteristically, these are formed with large machines, either as stretch forming of components which are welded into the whole, or as major sections which are formed or spun in toto and then assembled with fewer welds.

Technology advancements for this structure are concerned, in the main, with these major operations: stretching, tank forming, joining, inspecting and material handling. Details of the manufacturing lines incorporating these operations are described in the following sections.

The initial line (line 1) presumes a realistic, today's state-of-the-art situation where tank components are fabricated in one location and assembled in a second location. Of the several major Saturn V/Apollo components studied during Phase I, all were made in this manner—components were fabricated in one plant and assembled in another.

The details of the manufacturing processes, tools and material handling are summarized in Figure 5-1 for this propellant tank. The processes and tooling indicated in this figure are described in the following sections. The numbers on this chart correspond with the step numbers and can be correlated with later figures showing computer printouts.

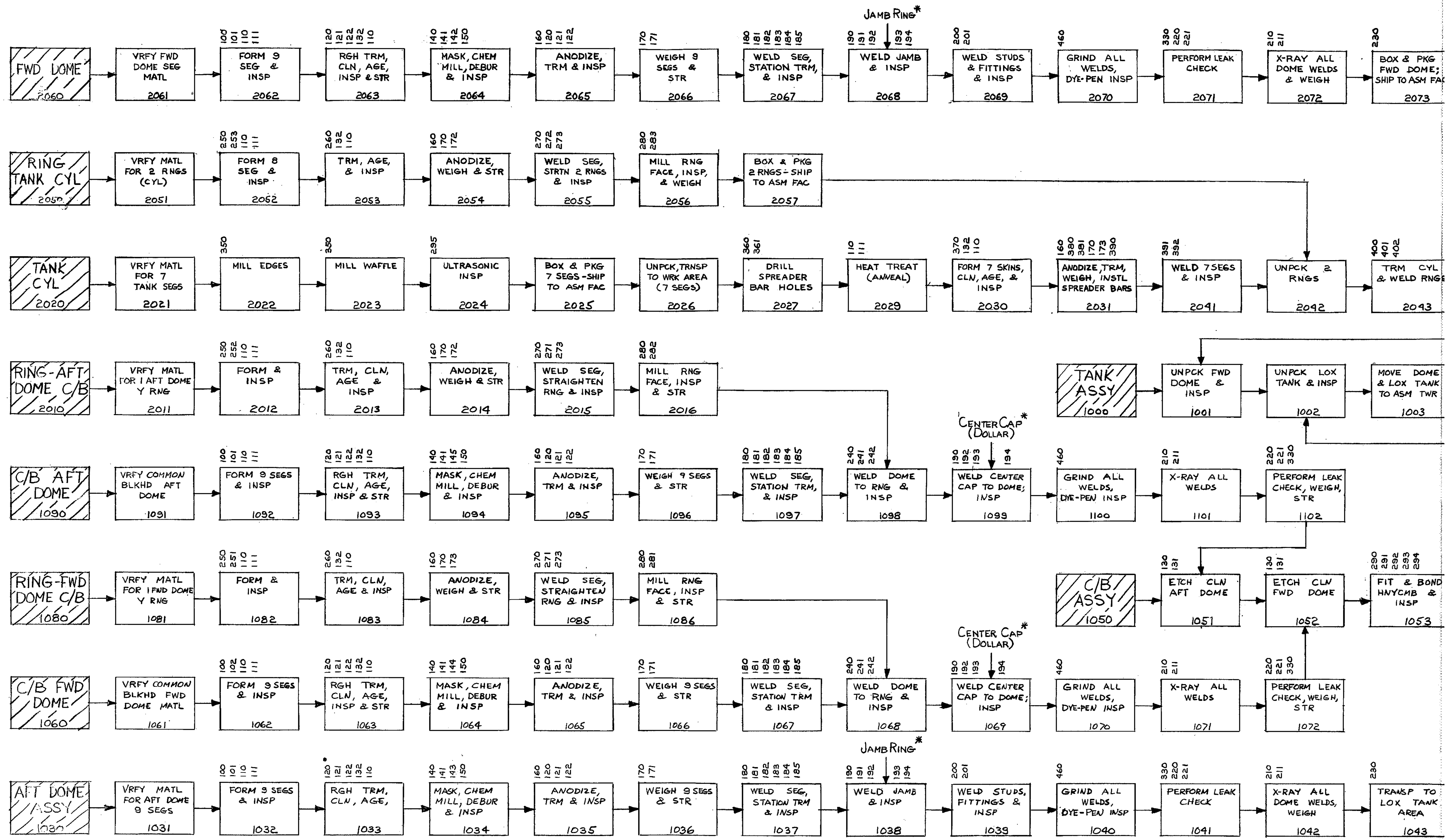
5.1.1.2 Manufacturing Processes and Methods

From References 3 through 6 and information gained during the Phase I manufacturing facility tours, the manufacturing processes were developed and sequence numbers were assigned for each defined detail component, subassembly, assembly, and finally the total tank assembly. Material costs were computed based upon dimensions shown in Figure 2-2, material thicknesses from the above reference, and the assumptions shown in Table 2-2.

As each manufacturing process was defined and placed into its respective sequence, a plant number also was assigned. An analysis was made of each of the manufacturing processes to determine its material cost as applicable and its man-hour requirements for machine setup time, manufacture, assembly, test, and quality control. The results of these analyses along with the defined and sequenced manufacturing processes are shown in Figure 5-2.

5.1.1.3 Tooling

Concurrent with the determination of man-hour requirements, and also based upon References 3 through 6 and the information gained during the Phase I manufacturing facility tours, tool requirements lists were developed on a component basis. Tool use times were estimated and the number of tools required for production rates of 2 and 20 per year were determined. The floor space requirements of each tool were determined from Reference 3 and other sources, such as the actual tool manufacturer. These floor space requirements were adjusted for walk-around clearance. Tooling unit costs were supplied by manufacturers or estimated by the General Electric Company tooling engineers. Tool identification, requirements, application, unit cost, and floor space requirements are shown in Table 5-1 for the production rates of 2 per year and 20 per year.



*PURCHASED PART

FOLD-OUT #1

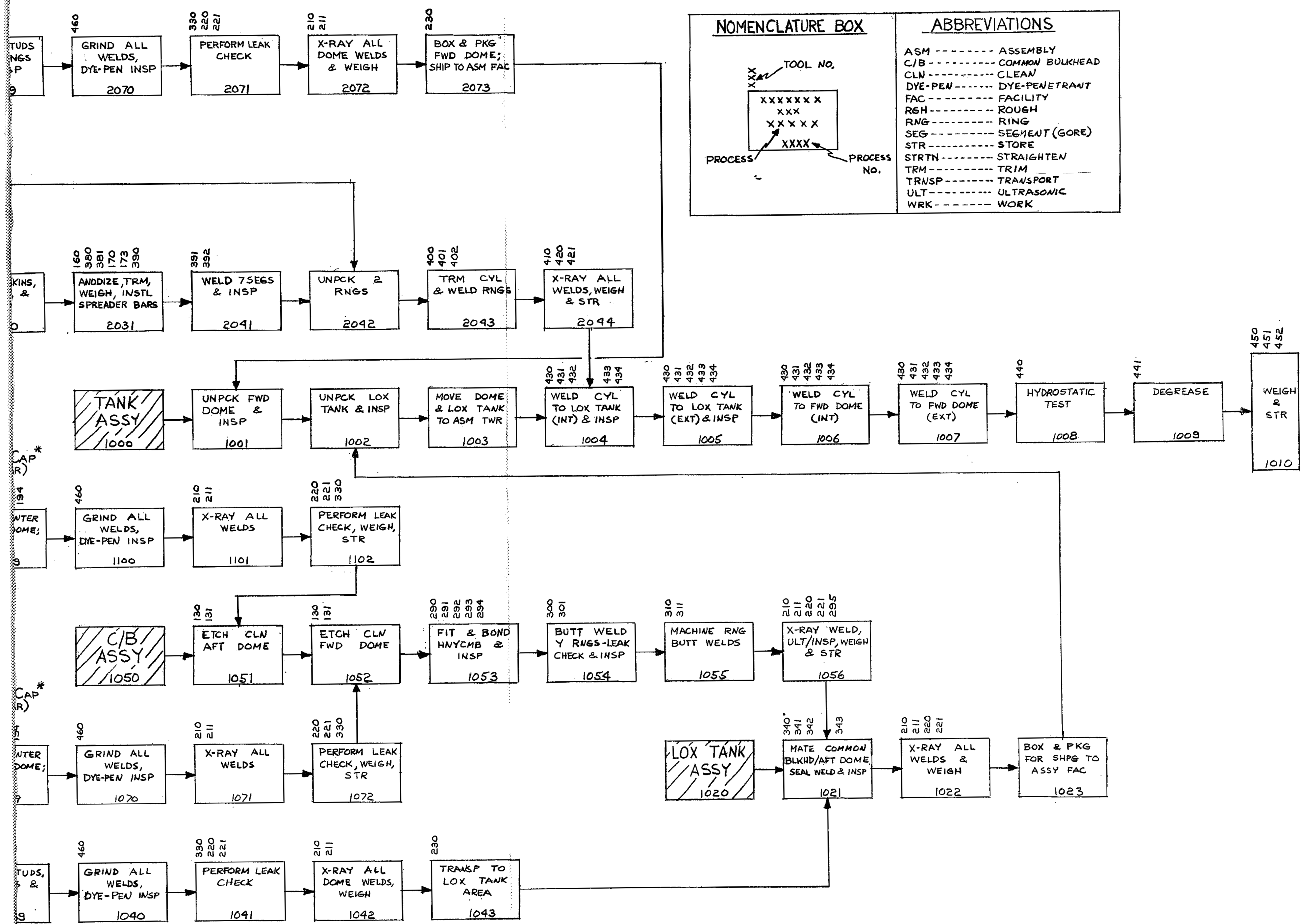


Figure 5-1. Typical Manufacturing Flow Diagram (Large L/V Liquid Hydrogen and Oxygen Tank)

Fold-Out #2

MANUFACTURING PRØCESSES	MAT'L CØST (K$)	Q.C. LABØR (M/HR)	MFG. LABØR (M/HR)	PLANT NØ.	TØTAL CØST (K$)
1000 TANK ASSEM					
1001 UNPACK FWD DØME & INSP	0	20	10	2	0.45
1002 UNPACK LØX DØME & INSPECT	0	40	10	2	0.75
1003 MØVE DØME&LX TK TØ ASM TWR	0	0	20	2	0.3
1004 WELD CYL TØ LX TK(INT)&INSP	0.62	112	172	2	4.88
1005 WELD CYL TØ LX TK(EXT)&INSP	0.62	52	52	2	2.18
1006 WELD CYL TØ FWD DØME(INT)	0.62	112	142	2	4.43
1007 WELD CYL TØ FWD DØME(EXT)	0.62	102	102	2	3.68
1008 HYDRØSTATIC TEST	0	200	400	2	9
1009 DEGREASE	0	50	100	2	2.25
1010 WEIGHT & STØRE	0	20	125	2	2.175
1020 LØX TANK ASSEM					
1021 MATE C BLK/A-DØM:SEAL & INSP	1.98	156	160	1	6.72
1022 X-RAY ALL WELDS, WEIGH	0.28	20	40	1	1.18
1023 BØX&PACK FØR SHPG TØ ASY FAC	0	5	10	1	0.225
1030 AFT DØME ASSEMBLY					
1031 VRFY MATL FØR AFT DØME-9 SEGS	3.5	0	0	1	3.5
1032 FØRM 9 SEGMENTS & INSPECT	0	102	180	1	4.23
1033 RØUGH TRIM, CLN, AGE, INSP&STRTN	0	18	89	1	1.605
1034 MASK, CHEM MILL, DEBURR & INSP	7.8	90	0	1	9.15
1035 ANØDIZE, TRIM, & INSPECT	0	18	27	1	0.675
1036 WEIGH 9 SEGMENTS & STØRE	0	5	9	1	0.21
1037 WELD SEGS, STATIØN TRIM & INSP	1.38	184	124	1	6
1038 WELD JAMB & INSPECT	0.28	13	18	1	0.745
1039 WELD STUDS, FITTINGS & INSPECT	0.22	19	23	1	0.85
1040 GRIND ALL WELDS, DIE-PEN INSP	0	60	200	1	3.9
1041 PERFØRM LEAK CHECK, WEIGH	0.1	10	30	1	0.7
1042 X-RAY ALL DØME WELDS, WEIGH	0.3	95	4	1	1.785
1043 TRANSP TØ LØX TANK AREA	0	5	10	1	0.225
1050 CØMMØN BULKHEAD ASSEM					
1051 ETCH CLEAN AFT DØME	0.2	15	30	1	0.875
1052 ETCH CLEAN FWD DØME	0.2	15	30	1	0.875
1053 FIT&BND HNYCMB & INSPECT	3.8	400	1600	1	33.8
1054 BUT WLD Y RNGS LK CHK&INSP	0.64	22	42	1	1.6
1055 MACHINE RING BUT WELDS	0	20	80	1	1.5
1056 XRAY WLD, ULT/INSP DØM, WGH&STR	4.24	30	10	1	4.84
1060 CØMMØN BLKHD FWD DØME					
1061 VRFY CMN BLKHD FWD DØM MATL	1.6	0	0	1	1.6
1062 FØRM 9 SEGMENTS & INSPECT	0	102	180	1	4.23
1063 RØUGH TRM, CLN, INSP & STØRE	0	18	89	1	1.605
1064 MASK, CHEM MILL, DEBUR&INSP	3.8	90	0	1	5.15
1065 ANØDIZE, TRIM & INSPECT	0	27	36	1	0.945
1066 WEIGH 9 SEGMENTS & STØRE	0	5	9	1	0.21
1067 WELD SEG STATIØN TRM &INSP	1.38	180	124	1	5.94
1068 WELD DØME TØ RING & INSPECT	0.64	26	34	1	1.54
1069 WLD CENT $CAP TØ DØME;INSP	0.28	13	20	1	0.775
1070 GRIND ALL WELDS, DIE-PEN INSP	0	60	200	1	3.9
1071 X-RAY ALL WELDS	0.46	0	0	1	0.46
1072 PERFØRM LEAK CHK, WEIGH, STØRE	0.1	15	40	1	0.925

Figure 5-2. Manufacturing Processes for Propellant Tank Structure (Element 2) State-of-the-Art Manufacturing Line (Line 1) (Sheet 1 of 3)

1080	RING-FWD DØME-CØMMØN BULK				
1081	VRY MAT FØR 1FWD DØM Y RNG	0.35	0	0	1	0.35
1082	FØRM & INSPECT	0	14	26	1	0.6
1083	TRM,CLN,AGE & INSPECT	0	4	14	1	0.27
1084	ANØDIZE,WEIGH & STØRE	0	4	8	1	0.18
1085	WLD SEG,STRAIGTEN RNG&INSP	0	40	80	1	1.8
1086	MILL RNG FACE, INSP&STØRE	0	25	50	1	1.125
1090	CØMMØN BULK AFT DØME					
1091	VRFY CØMMØN BLKHD AFT DØME	1.7	0	0	1	1.7
1092	FØRM 9 SEGMENTS & INSPECT	0	102	180	1	4.23
1093	RØUGH TRIM,CLN,AGE,INSP&STR	0	18	89	1	1.605
1094	MASK,CHM MILL,DEBUR & INSP	3.2	90	0	1	4.55
1095	ANØDIZE,TRIM & INSPECT	0	27	36	1	0.945
1096	WEIGH 9 SEGMENTS & STØRE	0	5	9	1	0.21
1097	WLD SEG STATIØN TRM&INSP	1.38	180	124	1	5.94
1098	WLD DØME TØ RING & INSPECT	0.64	26	34	1	1.54
1099	WLD CENT $CAP TØ DØME;INSP	0.28	13	20	1	0.775
1100	GRIND ALL WELDS,DIE-PEN INSP	0	60	200	1	3.9
1101	X-RAY ALL WELDS	0.46	0	0	1	0.46
1102	PERFØRM LEAK CHK,WEIGH,STØRE	0.1	15	40	1	0.925
2010	RING-AFT DØME CØMMØN BULK					
2011	VRFY MAT FØR 1AFT DØME Y RNG	0.35	0	0	1	0.35
2012	FØRM & INSPECT	0	14	26	1	0.6
2013	TRIM,CLEAN,AGE & INSPECT	0	4	14	1	0.27
2014	ANØDIZE,WEIGH & STØRE	0	4	8	1	0.18
2015	WLD SEG,STRAIGHTEN RNG&INSP	0	40	80	1	1.8
2016	MILL RNG FACE,INSPECT& STØRE	0	25	50	1	1.125
2020	TANK CYLINDER					
2021	VRFY MAT FØR 7 TANK SEGMEN	31	0	0	1	31
2022	MILL EDGES	6.5	28	56	1	7.76
2023	MILL WAFFLE	32.5	28	56	1	33.76
2024	ULTRASØNIC INSPECT	13.85	0	0	1	13.85
2025	BX PCK 7 SEG-SHP TØ ASM FAC	0	7	14	1	0.315
2026	UNPK,TRNSP TØ WK AREA(7 SEG)	0	7	14	2	0.315
2027	DRILL SPREADER BAR HØLES	0	14	28	2	0.63
2029	HEAT TREAT (ANNEAL)	0	0	14	2	0.21
2030	FØRM 7 SKINS,CLN,AGE,INSP	0	98	203	2	4.515
2031	ANDZ,TRM,WGH,INSTL SPR BARS	0	31	45	2	1.14
2041	WELD 7 SEGMENTS & INSP	2.2	106	212	2	6.97
2042	UNPACK 2 RINGS	0	5	10	2	0.225
2043	TRIM CYL & WELD RINGS	1.27	34	66	2	2.77
2044	XRAY ALL WLDS,WEIGH &STØRE	2.6	20	80	2	4.1
2050	RING TANK CYL					
2051	VRFY MAT FØR 2 RNGS(CYL)	0.7	0	0	1	0.7
2052	FØRM 8 SEG & INSPECT	0	28	52	1	1.2
2053	TRIM,AGE,INSPECT	0	8	28	1	0.54
2054	ANØDIZE WEIGH & STØRE	0	8	16	1	0.36
2055	WLD SEG,STRTN 2 RNGS&INSP	0	80	160	1	3.6
2056	MILL RNG FACE,INSP,WEIGH	0	45	90	1	2.025
2057	BX&PK 2 RGS-SHP TØ ASM FAC	0	5	10	1	0.225

Figure 5-2. Manufacturing Processes for Propellant Tank Structure (Element 2) State-of-the-Art Manufacturing Line (Line 1) (Sheet 2 of 3)

2060	FWD DØME					
2061	VRFY FWD DØME SEG MATL	1.8	0	0	1	1.8
2062	FØRM 9 SEG & INSPECT	0	102	180	1	4.23
2063	RGH TRM,CLN,AGE,INSP,STR	0	18	89	1	1.605
2064	MASK,CHEM MILL,DEBUR,INSP	3	90	0	1	4.35
2065	ANØDIZE,TRIM & INSPECT	0	18	27	1	0.675
2066	WEIGH 9 SEGMENTS & STØRE	0	5	9	1	0.21
2067	WELD SEG,STAT'NRY TRM,INSP	1.38	184	124	1	6
2068	WELD JAMB & INSPECT	0.28	13	18	1	0.745
2069	WELD STUDS&FITTINGS &INSP	0.22	19	23	1	0.85
2070	GRIND ALL WELDS,DIE-PEN INSP	0	60	200	1	3.9
2071	PERFØRM LEAD CHECK	0.1	10	30	1	0.7
2072	X-RAY ALL DØME WELDS,WEIGH	0.3	95	4	1	1.785
2073	BX&PK FWD DØM;SHP TØ ASY FAC	0	5	10	1	0.225

	PLANT 1	PLANT 2	TØTAL
MANUFACTURING PRØCESSES 0.5 YR CØST-(K$)	270.31	50.97	321.28
MATERIAL CØST-(K$)	133.27	8.55	141.82
QUALITY CØNTRØL LABØR-(M/HRS)	3404	1023	4427
-(K$)	51.06	15.345	66.405
MANUFACTURING LABØR-(M/HRS)	5732	1805	7537
-(K$)	85.98	27.075	113.055

Figure 5-2. Manufacturing Processes for Propellant Tank Structure (Element 2) State-of-the-Art Manufacturing Line (Line 1) (Sheet 3 of 3)

Table 5-1

PROPELLANT TANK STRUCTURE

TOOL REQUIREMENTS/APPLICATION/UNIT COST

LINE #1

TOOL IDENTIFICATION		UNIT COST $/K	APPLICATION													*PER TOOL
			DOME		COMMON BULKHEAD					TANK CYLINDER			TANK ASSEMBLY	PROD		ALLOWABLE SQ. FOOTAGE *
					DOME		RING									
NO.	NAME		FWD	AFT	FWD	AFT	FWD	AFT	ASSY	CYL	RING	ASSY		2/YEAR	20/YEAR	
100	Stretch Press	650.0	X	X	X	X								1	3	260
101	Stretch Form Die No. 1	30.0	X	X		X								1	2	-
102	Stretch Form Die No. 2	30.0			X									1	1	-
110	Heat Treat Oven (12'x12'x40')	200.0	X	X	X	X	X	X		X	X			1	2	1000
111	Quench Tank (12'x12'40')	50.0	X	X	X	X	X	X		X	X			1	1	1000
120	Dome Segment Trim Tool	20.0	X	X	X	X								1	1	500
121	Dome Segment Cutter	5.0	X	X	X	X								1	1	-
122	Work Stand	1.0	X	X	X	X								2	2	-
130	Dome Rotating Tool	125.0			X	X								1	1	600
131	Etch Cleaning Tank (25'x25'x12')	50.0			X	X								1	1	1200
132	Etch Cleaning Tank (12'x12'x40')	50.0	X	X	X	X	X	X		X	X			1	1	1000
140	Spray Booth	20.0	X	X	X	X								1	1	1000
141	Neoprene Maskant Spray	2.0	X	X	X	X								1	1	-
142	Maskant Cut Stencil No. 1	.5	X											1	5	-
143	Maskant Cut Stencil No. 2	.5		X										1	5	-
144	Maskant Cut Stencil No. 3	.5			X									1	5	-
145	Maskant Cut Stencil No. 4	.5				X								1	5	-
150	Chem Mill 12'x12'x12'	25.0	X	X	X	X								1	2	1000
160	Anodize 12'x12'x40'	25.0	X	X	X	X	X	X		X	X			2	4	1000
170	Load Cell No. 1	2.0	X	X	X	X	X	X		X	X			1	1	-
171	Hoist Spreader Bar No. 1	.8	X	X	X	X								2	4	10
172	Hoist Spreader Bar No. 2	.8					X	X			X			2	4	10
173	Hoist Spreader Bar No. 3	.8								X				1	2	10

Table 5-1 (Continued)

PROPELLANT TANK STRUCTURE

TOOL REQUIREMENTS/APPLICATION/UNIT COST
LINE #1

TOOL IDENTIFICATION			APPLICATION													*PER TOOL
NO.	NAME	UNIT COST $/K	DOME		COMMON BULKHEAD					TANK CYLINDER			TANK ASSEMBLY	PROD		* ALLOWABLE SQ. FOOTAGE
					DOME		RING									
			FWD	AFT	FWD	AFT	FWD	AFT	ASSY	CYL	RING	ASSY		2/YEAR	20/YEAR	
180	Meridian Welder	100.0	X	X	X	X								1	3	1500
181	Clamp Bar	20.0	X	X	X	X								1	3	-
182	Welding Head Stand	30.0	X	X	X	X								1	3	500
183	Welding Head	10.0	X	X	X	X								1	3	-
184	Station Trimmer	10.0	X	X	X	X								1	3	-
185	X-ray Unit	18.0	X	X	X	X								1	3	-
190	Jamb Ring Welder Stand	30.0	X	X	X	X								1	2	1800
191	Jamb Clamps	2.0	X	X										1	2	-
192	Jamb Ring/Dollar Opening Trimmer	5.0	X	X	X	X								1	2	-
193	Jamb Ring/Dollar Welder	7.0	X	X	X	X								1	2	-
194	X-ray	18.0	X	X	X	X								1	2	-
200	Pick Up Positioner	7.0	X	X										1	2	2000
201	Stud Welder Head	10.0	X	X										1	2	-
210	X-ray Holding Fixture	15.0	X	X	X	X			X					1	4	1000
211	X-ray Unit	18.0	X	X	X	X			X					1	4	-
220	Spreader Bar No. 4 (Hoist)	.8	X	X	X	X			X					1	4	10
221	Load Cell No. 2	2.0	X	X	X	X			X					1	2	10
230	Transport Fixture	4.0	X	X										2	6	1000
240	Dome to Ring Weld Fixture	12.0			X	X								1	1	1200
241	Welding Head	18.0			X	X								1	1	-
242	X-ray Unit	18.0			X	X								1	1	-
250	Stretch Press	20.0					X	X			X			1	1	72
251	Ring Die No. 1	2.0					X							1	1	-
252	Ring Die No. 2	2.0						X						1	1	-

Table 5-1 (Continued)

PROPELLANT TANK STRUCTURE

TOOL REQUIREMENTS/APPLICATION/UNIT COST LINE #1																
TOOL IDENTIFICATION			APPLICATION													*PER TOOL
		UNIT COST $/K	DOME		COMMON BULKHEAD					TANK CYLINDER				PROD		
					DOME		RING									
NO.	NAME		FWD	AFT	FWD	AFT	FWD	AFT	ASSY	CYL	RING	ASSY	TANK ASSEMBLY	2/YEAR	20/YEAR	ALLOWABLE * SQ. FOOTAGE
253	Ring Die No. 3	2.0									X			1	1	-
260	Ring Extrusion Cutter	.5					X	X			X			1	1	100
270	Ring Weld Fixture	20.0					X	X			X			1	1	400
271	Ring Weld Fixture Set No. 1	1.0					X	X						1	1	-
272	Ring Weld Fixture Set No. 2	1.0									X			1	1	-
273	Welding Head	10.0					X	X			X			1	1	-
280	Vertical Boring Mill	350.0					X	X			X			1	1	2000
281	Lathe Fixture No. 1	12.0					X							1	1	-
282	Lathe Fixture No. 2	12.0						X						1	1	-
283	Lathe Fixture No. 3	12.0									X			1	1	-
290	Bonding Gantry	40.0							X					1	4	6400
291	Heat/Pressure Dome	80.0							X					1	4	-
292	Vacuum Bag	8.0							X					1	4	-
293	Bleeder Cloth	2.0							X					1	4	-
294	Vacuum Pump	2.0							X					1	4	-
295	Sonic Measuring Device and	25.0							X	X				1	4	500
	Automatic Read Out								X	X				1	4	500
300	Common Bulkhead Ring Butt Weld Fixture	8.0							X					1	2	1000
301	Welding Head	18.0							X					1	2	-
310	Common Bulk Lathe Fixture	12.0							X					1	1	1000
311	Ring Cutting Tool	1.0							X					1	1	100
320	Spreader Bars (Hoist)	1.0							X					1	2	50
321	Load Cell	2.0							X					1	2	-
330	Ammonia Gas Pressure Test Rig	10.0	X	X	X	X			X					2	6	1000

Table 5-1 (Continued)

PROPELLANT TANK STRUCTURE

TOOL REQUIREMENTS/APPLICATION/UNIT COST
LINE #1

TOOL IDENTIFICATION			APPLICATION													*PER TOOL
NO.	NAME	UNIT COST $/K	DOME		COMMON BULKHEAD					TANK CYLINDER			TANK ASSEMBLY	PROD		* ALLOWABLE SQ. FOOTAGE
					DOME		RING									
			FWD	AFT	FWD	AFT	FWD	AFT	ASSY	CYL	RING	ASSY		2/YEAR	20/YEAR	
340	LOX Tank Weld Fixture	35.0							X					1	3	2000
341	Drill	1.0							X					1	3	-
342	Drill Jigs	2.0							X					1	3	-
343	Welder	18.0							X					1	3	-
350	Skin Mill (10'x40')	500.0								X				1	1	1500
360	Drill Template	.5								X				2	4	-
361	Power Drill	1.0								X				2	4	-
370	Brake - 40'	150.0								X				1	1	2000
380	Segment Trim Fixture	35.0								X				1	2	500
381	Power Cutter	5.0								X				1	2	-
390	Spreader Bars	2.8										X		1 Set	2 Sets	500
391	Longitudinal Weld Fixture	45.0										X		1	2	1200
392	Welder Head	18.0										X		1	2	-
400	End Trim/Ring Weld Dolly	75.0										X		1	2	1000
401	Weld Fixture	5.0										X		1	2	-
402	Welder Head	18.0										X		1	2	-
410	X-ray	18.0										X		1	1	2000
420	Hoist Spreader Bar	1.5										X		2	4	10
421	Load Cell	2.0										X		1	2	-
430	Tank Assem Tower	200.0											X	1	6	2000
431	Heat Blanket	12.0											X	1	6	-
432	Welder Head	18.0											X	1	6	-
433	X-ray	18.0											X	1	6	-

PLANT 1

PLANT 2

Table 5-1 (Continued)

PROPELLANT TANK STRUCTURE

TOOL REQUIREMENTS/APPLICATION/UNIT COST LINE #1																
TOOL IDENTIFICATION			APPLICATION													*PER TOOL
			DOME		COMMON BULKHEAD					TANK CYLINDER				PROD		
					DOME		RING									
NO.	NAME	UNIT COST $/K	FWD	AFT	FWD	AFT	FWD	AFT	ASSY	CYL	RING	ASSY	TANK ASSEMBLY	2/YEAR	20/YEAR	ALLOWABLE * SQ. FOOTAGE
434	Hoisting Yoke and Crane	50.0											X	1	6	-
440	Hydrostatic Test Equip	100.0											X	1	6	2000
441	Degreaser	80.0											X	1	6	2000
450	Tank Dolly	40.0											X	1	6	1000
451	Hoist Yoke	10.0											X	1	6	-
452	Load Cell	2.0											X	1	6	-
460	Weld Grinder (Portable)	1.0	X	X	X	X	X	X		X	X			3	6	10

5.1.1.4 Manufacturing Plant

In the determination of cost of the facilities to house the two state-of-the-art manufacturing lines, one having a production rate of 2 per year and the other 20 per year, it was assumed that each line would have a manufacturing plant (plant 1) and an assembly plant (plant 2). It was estimated that plant 1 for both lines would require 30-foot ceilings and plant 2 for both lines would require 100-foot ceilings. These estimates were based upon the size of subassemblies, the tank assembly, tooling requirements, and overhead bridge crane clearances.

The floor area for each of the buildings was established based upon providing facilities for the number of personnel required and summarizing the floor area requirements for the tooling and adjusting for other elements as shown in Tables 5-2 and 5-3.

In arriving at the total cost of each of the manufacturing plants, land cost based upon 1969 real estate values of land designated commercial, near transportation, in the vicinity of Daytona Beach, Florida were set at $12,000 per acre plus $18,500 per acre for improvement (access roads, water, etc.). Other cost items, including $18 per square foot of floor area, were estimated based upon information contained in Reference 2 and information provided by the General Electric Company facilities section. The total cost of each of the manufacturing plants is summarized in Table 5-4.

Table 5-2

Propellant Tank Structure (Element 2) and State-of-the-Art (Line 1) Manufacturing Plant (Low Bay - 30-Foot) Floor Areas

PRODUCTION RATE	2 Per Year	20 Per Year
NO. OF PERSONNEL*	250	750
ITEM	Floor Area Square Feet	Floor Area Square Feet
Machine and Tool Area (from Table 5-1 + 50%)	54,363	184,384
Center Aisle and Entry Area	18,250	40,250
Storage Areas—Materials	12,200	39,200
Eating Area	3,750	4,750
Loading Dock Extensions	2,000	5,000
Office Space	1,000	1,300
Dispensary	1,120	1,120
Toilet Facilities	600	800
Fork Lift Parking Area	90	120
Clean Room Facility and Compressor Area	29,362	46,666
Vending Machine Area	45	60
Total	122,780	323,650

*For Facility Sizing Only

Table 5-3

Propellant Tank Structure (Element 2) and State-of-the-Art (Line 1)
Assembly Plant (High Bay - 100-Foot) Floor Areas

PRODUCTION RATE	2 Per Year	20 Per Year
NO. OF PERSONNEL*	200	600
ITEM	Floor Area Square Feet	Floor Area Square Feet
Machine and Tool Area (from Table 5-1 + 50%)	21,300	78,660
Center Aisle and Entry Area	18,000	45,000
Storage Area—Materials and Assemble Vehicle	45,660	100,000
Eating Area	3,100	4,100
Loading Dock Extension (2)	5,000	12,500
Office Space	1,000	1,100
Dispensary Area	1,120	1,120
Toilet Facilities	600	800
Fork Lift Parking Area	90	180
Transporter Area	1,900	3,800
Vending Machine Area	50	75
Total	97,820	247,335

*For Facility Sizing Only

In arriving at the total cost of each of the assembly plants, land cost based upon 1969 real estate values of land designated commercial near transportation, including the intracoastal waterway, in the vicinity of Cape Kennedy (north entrance) were set at $14,500 per acre plus $18,500 per acre for improvements (access roads, water, etc.). Other cost items including $60 per square foot of floor area were estimated based upon information contained in Reference 2 and information provided by the General Electric Company facilities section. The total cost of each of the assembly plants is summarized in Table 5-5.

5.1.1.5 Transportation

Transportation cost estimates include the costs encountered in moving subassemblies and components from plant 1 to plant 2. The basic elements of cost are re-usable shipping containers and the actual hauling charges. For this estimate it was assumed that the distance from plant 1 to plant 2 was 100 miles. It was further assumed that for a production rate of 2 per year, one set of containers would be required while 3 sets of containers would be necessary for a production rate of 20 per year.

Table 5-4

Land Acquisition and Building Construction Requirements/Cost
Propellant Tank Structure (Element 2) and State-of-the-Art Manufacturing Line (Line 1)
Plant No. 1—Manufacturing (Low Bay - 30 Feet)

2 Per Year		20 Per Year	
Item	($) Cost	Item	($) Cost
Land—4.5 Acres (Including Required Improvements)	137,250	Land—8.25 Acres (Including Required Improvements)	251,625
Sewage Plant	247,000	Sewage Plant	280,000
Main Plant^{x} (122,780 square feet)	2,210,040	Main Plant^{x} (323,650 square feet)	5,825,692
Outside Storage Sheds	20,000	Outside Storage Sheds	47,500
Dock Requirements	8,500	Dock Requirements	11,000
Dispensary	30,000	Dispensary	32,000
Bridge Crane (10-Ton)	30,000	Bridge Cranes (2 10-Ton, 1 5-Ton)	75,000
Wall Partitions (Portable), Doors, Storage Bins, etc.	68,000	Wall Partitions (Portable), Doors, Storage Bins, etc.	150,000
Toilet Fixtures	11,400	Toilet Fixtures	14,500
Office Furniture	4,000	Office Furniture	5,000
Air Lines, Compressor and Fire Protection System*	100,000	Air Lines, Compressors (3), and Fire Sprinkler System**	200,000
Clark Fork Lift Trucks (3)	15,000	Clark Fork Lift Trucks (4) and Tugs (2)	33,000
Total	2,881,190	Total	6,925,317

* One Clean Room Included
** Two Clean Rooms Included
x Building—Temperature Controlled—Air Conditioned, Heated and Insulated—$18 per square foot

Table 5-5

Land Acquisition and Building Construction Requirements/Cost
Propellant Tank Structure (Element 2) and State-of-the-Art Manufacturing Line (Line 1)
Plant No. 2—Assembly (High Bay Type - 100 Feet)

2 Per Year		20 Per Year	
Item	($) Cost	Item	($) Cost
Land—3.75 Acres (Including Required Improvements)	123,750	Land—6.75 Acres (Including Required Improvements)	222,750
Sewage Plant	200,000	Sewage Plant	230,000
Main Plant[x] (97,820 square feet)	5,869,300	Main Plant[x] (247,335 square feet)	14,840,100
Outside Storage Sheds	20,000	Outside Storage Sheds	47,500
Dock Requirements	8,300	Dock Requirements	18,000
Dispensary	30,000	Dispensary	32,000
Bridge Crane (20-Ton 30-Foot Span)	60,000	Bridge Crane (2 20-Ton 30-Foot Span, 1 10-Ton and 1 5-Ton)	165,000
Wall Partitions (Portable) Doors (Elec. Operated) and Storage Bins, Fixtures, etc.	83,000	Wall Partitions (Portable) Doors (Elec. Operated) and Storage Bins, Fixtures, etc.	155,000
Toilet Fixtures	11,500	Toilet Fixtures	14,500
Office Furniture	4,000	Office Furniture	5,000
Air Lines, Compressors, and Fire Protection System	70,000	Air Lines, Compressors, and Fire Protection System	140,000
Fork Lift Trucks (3) and Tugs (2)	23,000	Fork Lift Trucks (5) and Tugs (2)	38,000
Total	6,502,850	Total	15,907,850

x Building—Temperature Controlled—Air Conditioned, Heated and Insulated—$60 per square foot

All transportation costs, including the cost of the containers, were estimated based upon the size and weight of the components to be carried. The container estimates were prepared by the Apollo Systems shipping department and the hauling charges were estimated by a local cargo carrier. Containers costs are shown in Table 5-6.

The estimated hauling cost, one way with containers full, and a return trip with the containers empty, is shown in Table 5-7.

Table 5-6

Shipping Container Cost
Propellant Tank Structure (Element No. 2)

	Production Rate 2 Per Year	Production Rate 20 Per Year
Container Identification	Number Req/Cost	Number Req/Cost
LOX Tank 22' x 22' x 15' - bolted Sections, shock mounted, Cross braced structure, webb Belt tie downs - wt = 2900 lbs.	1/$8,600	3/$25,800
Upper Dome 22' x 22' x 13' - same as above - wt = 2200 lbs.	1/$7,000	3/$21,000
Rings (cyl, in pairs) 22' x 22' x 2' - same as above - wt = 1100 lbs.	1/$4,400	3/$13,200
Cylinder Sections 35' x 10' x 6' - same as above - wt = 2050 lbs.	1/$4,100	3/$12,300
Total Cost (Non-Recurring)	1 set/$24,100	3 sets/$72,300

Table 5-7

Transportation Cost Summary—Leased Mover
Plant No. 1 to Plant No. 2 One Way Distance - 100 Miles
Propellant Tank Structure (Element 2)

Containers	Cost Full One Way	Cost Empty One Way	Round Trip Per Tank
LOX Tank Upper Dome	$1,500	$ 600	
Rings (Cyl) Cylinder Sections	1,300	500	
Total Cost (Recurring)	$2,800	$1,100	$3,900

5.1.1.6 Near-Term Pre-Manufacturing Operations

Table 5-8 presents the near-term pre-manufacturing operations non-recurring and recurring man-hour requirements. These man-hour requirements are the result of estimates developed using manufacturing consultants within the General Electric Company and through visits with aerospace manufacturers. The non-recurring man-hours are estimated on a total program basis and are subject to a 40-percent recycle factor during the life of the program for updating the re-evaluation of functions. The recurring man-hours are on a per-vehicle basis. Both the non-recurring (including the 40-percent recycle factor) and recurring man-hours are shown in Table 5-8.

5.1.1.7 Summary

The detail cost elements for production rates of 2 and 20 tanks per year are shown in Tables 5-9 and 5-10. A summary for each cost calculation is shown on the respective tables.

Table 5-8

Near-Term Pre-Manufacturing Operations for Propellant Tank Structure (Element 2)
State-of-the-Art Manufacturing Line (Line 1)

NEAR-TERM PRE-MANUFACTURING ØPERATIØNS

NØN-RECURRING CØSTS

ITEM	M/HRS	TØTAL CØST (K$)
800 REVIEW PRØGRAM DIRECTIVES	700.	10.5
810 MFG. PRELIMINARY SCHEDULES	700.	10.5
820 PRØDUCIBILITY STUDIES	9380.	140.7
830 IDENTIFY/ØRDER LØNG LEAD ITEMS	1890.	28.35
840 ACCUMULATE/REVIEW ENGR & QC DØCUMENT.	1890.	28.35
850 DEVELØP SUB-ASSEMBLY & PARTS SCHEDULE	9380.	140.7
860 MFG. PLANNING ØPERATIØNS	14000.	210
870 DESIGN/PRØCURE TØØLING	22400.	336
880 VENDØR EVALUATIØN & SELECTIØN	4200.	63
NØN-RECURRING TØTALS	64540.	968.1

RECURRING CØSTS

ITEM	M/HRS	TØTAL CØST (K$)
900 EXPEDITE IN-HØUSE/PURCHASE PARTS	800.	12
910 REVIEW PRØGRESS WITH PRØGRAM ØFFICE	200.	3
RECURRING TØTALS	1000	15

TØTAL RECURRING AND NØN-RECURRING PRE-MFG. CØSTS= 983.1

Table 5-9

Manufacturing Cost Analysis

MANUFACTURING COST ANALYSIS
****
09/22/70

LINE: IMPROVED MANUFACTURING LINE (LINE 2)

STRUCTURE: PROPELLANT TANK STRUCTURE (ELEMENT 2)

PRODUCTION RATE: 2 PER YEAR

VARIATION FROM THE NOMINAL: NONE

TOTAL PROGRAM LENGTH: 5 YEARS

LABOR RATES-($/HR): PRE-MFG.- 15. ; Q.C.- 15. ; MFG.- 15.

TOOLING	UNIT COST (K$)	NO. UNITS	TOTAL COST (K$)
100 POWER SAW	8	1	8
101 WORK PLATFORM	2	1	2
102 SCRIBE ARM	1	1	1
110 VERTICAL BORING MILL	350	1	350
111 ROLLERS	25	1	25
112 STAKE	25	1	25
113 HEAT MANIFOLD	35	1	35
114 STATION CUTTER	15	1	15
120 LATHE FIXTURE # 1	12	1	12
121 LATHE FIXTURE # 2	12	1	12
122 LATHE FIXTURE # 3	12	1	12
140 HEAT TREAT OVEN (25'X25'X40')	350	1	350
141 QUENCH TANK (25'X25'X40')	100	1	100
150 DOME ROTATING TOOL	125	1	125
151 ETCH CLEANING TANK (25'X25'X12')	50	1	50
152 ETCH CLEANING TANK (25'X25'X40')	100	1	100
160 JAMB RING WELDER STAND	30	1	30
161 JAMB CLAMPS	2	1	2
162 JAMB RING/DOLLAR OPENING TRIMMER	5	1	5
163 JAMB RING/DOLLAR WELDER	7	1	7
164 X-RAY UNIT	18	1	18
170 SPRAY BOOTH	20	1	20
171 NEOPRENE MASKANT SPRAY	4	1	4
172 MASKANT CUT STENCIL # 1	1	4	4
173 MASKANT CUT STENCIL # 2	1	4	4
174 MASKANT CUT STENCIL # 3	1	4	4
175 MASKANT CUT STENCIL # 4	1	4	4
180 CHEM MILL (25'X25'X12')	75	1	75
190 ANODIZE (25'X25'X40')	75	2	150
200 LOAD CELL # 1	2	1	2
201 HOIST SPREADER BAR #1	0.8	1	0.8
202 HOIST SPREADER BAR #2	0.8	1	0.8
203 HOIST SPREADER BAR #3	0.8	1	0.8
204 PICKUP POSITIONER	7	1	7
205 STUD WELDER HEAD	10	1	10
210 WELD GRINDER(PORTABLE)	1	3	3
220 AMMONIA GAS PRESSURE TEST RIG	10	1	10
230 X-RAY HOLDING FIXTURE	15	1	15
231 X-RAY UNIT	18	1	18
240 TRANSPORT FIXTURE	4	2	8
250 DOME TO RING WELD FIXTURE	12	1	12
251 WELDING HEAD	18	1	18
252 X-RAY UNIT	18	1	18
260 STRETCH PRESS	20	1	20
261 RING DIE #1	2	1	2
262 RING DIE #2	2	1	2
263 RING DIE #3	2	1	2
270 RING EXTRUSION CUTTER	0.5	1	0.5
271 RING WELD FIXTURE	20	1	20
272 RING WELD FIXTURE SET 1	1	1	1
273 RIND WELD FIXTURE SET 2	1	1	1
274 WELDING HEAD	10	1	10
280 BONDING GANTRY	40	1	40
281 HEAT/PRESSURE DOME	80	1	80
282 VACUUM BAG	8	1	8
283 BLEEDER CLOTH	2	1	2
284 VACUUM PUMP	2	1	2
285 SONIC MEASURING DEVICE& AUTO RDOUT	25	1	25
290 COMMON BULKH RING BUTT WLD FIXT	8	1	8
291 WELDING HEAD	18	1	18
300 COM BULKH LATHE FIXTURE	12	1	12
301 RING CUTTING TOOL	1	1	1
310 SPREADER BARS(HOIST)	1	1	1
311 LOAD CELL	2	1	2
320 LOX TANK WELD FIXTURE	35	1	35
321 DRILL	1	1	1
322 DRILL JIG	2	1	2
323 WELDER	18	1	18
330 SKIN MILL(10'X40')	500	1	500
340 DRILL TEMPLATE	0.5	2	1
341 POWER DRILL	1	2	2
350 BRAKE-40'	150	1	150
360 SEGMENT TRIM FIXTURE	35	1	35
361 POWER CUTTER	5	1	5
370 SPREADER BARS	0.2	14	2.8
371 LONGITUDINAL WELD FIXTURE	45	1	45
372 WELDER HEAD	18	1	18
380 END TRIM/RING WELD DOLLY	75	1	75
381 WELD FIXTURE	5	1	5
382 WELDER HEAD	18	1	18
410 X-RAY UNIT	18	1	18
420 HOIST SPREADER BAR	1.5	2	3
421 LOAD CELL	2	1	2

TOOLING	UNIT COST (K$)	NO. UNITS	TOTAL COST (K$)
430 TANK ASSEM TOWER	200	1	200
431 HEAT BLANKET	12	1	12
432 WELDER HEAD	18	1	18
433 X-RAY UNIT	18	1	18
434 HOISTING YOKE & CRANE	50	1	50
440 HYDROSTATIC TEST EQUIP	100	1	100
441 DEGREASER	80	1	80
450 TANK DOLLY	40	1	40
451 HOIST YOKE	10	1	10
452 LOAD CELL	2	1	2
TOTAL TOOLING COST (K$)			3395.7

FACILITIES	TOTAL COST (K$)
500 CONSOLIDATED MANUFACTURING & ASSEMBLY PLANT	6972

NEAR-TERM PRE-MANUFACTURING OPERATIONS

NON-RECURRING COSTS

ITEM	M/HRS	TOTAL COST (K$)
800 REVIEW PROGRAM DIRECTIVES	700.	10.5
810 MFG. PRELIMINARY SCHEDULES	700.	10.5
820 PRODUCIBILITY STUDIES	9380.	140.7
830 IDENTIFY/ORDER LONG LEAD ITEMS	1890.	28.35
840 ACCUMULATE/REVIEW ENGR & QC DOCUMENT.	1890.	28.35
850 DEVELOP SUB-ASSEMBLY & PARTS SCHEDULE	9380.	140.7
860 MFG. PLANNING OPERATIONS	14000.	210
870 DESIGN/PROCURE TOOLING	22400.	336
880 VENDOR EVALUATION & SELECTION	4200.	63
NON-RECURRING TOTALS	64540.	968.1
RECURRING COSTS		
900 EXPEDITE IN-HOUSE/PURCHASE PARTS	8000.	120
910 REVIEW PROGRESS WITH PROGRAM OFFICE	2000.	30
RECURRING TOTALS	10000	150
TOTAL RECURRING AND NON-RECURRING PRE-MFG. COSTS=		1118.1

MANUFACTURING PROCESSES	MAT'L COST (K$)	Q.C. LABOR (M/HR)	MFG. LABOR (M/HR)	TOTAL COST (K$)
1000 TANK ASSEMBLY				
1001 INSPECT FWD DOME	0	200	100	4.5
1002 INSPECT LOX TANK	0	400	100	7.5
1003 MOVE F/D+L/T TO ASSY TOWER	0	0	200	3
1004 WELD CYL TO L/T(INTER)+INSP	6.2	1120	1720	48.8
1005 WELD CYL TO L/T(EXTER)+INSP	6.2	520	520	21.8
1006 WELD CYL TO F/D(INTER)+INSP	6.2	1120	1420	44.3
1007 WELD CYL TO F/D(EXTER)+INSP	6.2	1020	1020	36.8
1008 HYDROSTATIC TEST	0	2000	4000	90
1009 DEGREASE	0	500	1000	22.5
1010 WEIGH+STORE	0	200	1250	21.75
1020 LOX TANK ASSEMBLY				
1021 MATE C/B+A/D(SEAL WELD+INSP	19.8	1560	1600	67.2
1022 X-RAY ALL WELDS+WEIGH	2.8	200	400	11.8
1023 MOVE TO A/A	0	50	100	2.25
1030 AFT DOME ASSY				
1031 VERIFY MTL FOR A/D	26	0	0	26
1032 SCRIBE+SAW BLK TO REQ SHAPE	0	160	320	7.2
1033 SHEAR SPIN FORM+INSP	0	200	460	9.9
1034 CLEAN+ANNEAL+QUENCH+INSP	0	240	320	8.4
1035 SPIN FORM TO SHAPE+INSP	0	300	600	13.5
1036 CLEAN+ANNEAL+QUENCH+INSP	0	240	320	8.4
1037 FINAL FORMSPIN+STA TRIM+INSP	0	300	600	13.5
1038 CUT+TRIM C/C OPNG+DEBURR+INSP	0	80	260	5.1
1039 CLN+HEAT TREAT+AGE+INSP+STORE	0	300	540	12.6
1040 MASK+CHEM MILL+DEBURR+INSP	78	900	0	91.5
1041 CLEAN+ANODIZE+INSP	0	180	270	6.75
1042 WEIGH+STORE	0	50	90	2.1
1043 WELD JAMB+INSP	2.8	130	180	7.45
1044 WELD STUDS+FITTINGS+INSP	2.2	190	230	8.5
1045 GRIND ALL WELDS+DYE-PEN INSP	0	600	2000	39
1046 PERFORM LEAK CHECK	1	100	300	7
1047 X-RAY ALL DOME WELDS+WEIGH	3.	950	40	17.85
1048 TRANSPORT TO L/T A/A	0	50	100	2.25
1050 COMMON BULKHEAD ASSY				
1051 ETCH CLEAN AFT DOME	2	150	300	8.75
1052 ETCH CLEAN FWD DOME	2	150	300	8.75
1053 FIT+BOND HONEYCOMB+INSP	38	4000	16000	338
1054 BUTT WELD Y RINGS+LK CK+INSP	6.4	220	420	16
1055 MACHINE RING BUTT WELDS	0	200	800	15
1056 X-RAY WELD+U/I DOME+WGH+STORE	42.4	300	100	48.4
1060 COMMON BULKHEAD F/D				
1061 VERIFY MTL FOR C/B F/D	8	0	0	8
1062 SCRIBE+SAW BLK TO REQ SHAPE	0	160	320	7.2
1063 SHEAR SPIN FORM+INSP	0	200	460	9.9
1064 CLEAN+ANNEAL+QUENCH+INSP	0	240	320	8.4
1065 SPIN FORM TO SHAPE+INSP	0	300	600	13.5
1066 CLEAN+ANNEAL+QUENCH+INSP	0	240	320	8.4
1067 FINAL FORM SPIN+STA TRIM+INSP	0	300	600	13.5
1068 CUT+TRIM C/C OPNG+DEBURR+INSP	0	80	260	5.1
1069 CLN+HEAT TREAT+AGE+INSP+STORE	0	300	540	12.6
1070 MASK+CHEM MILL+DEBURR+INSP	38	900	0	51.5
1071 CLEAN+ANODIZE+INSPECT	0	270	360	9.45
1072 WELD DOME TO RING+INSP	6.4	260	340	15.4
1073 WELD CENTER CAP TO DOME+INSP	2.8	130	200	7.75
1074 GRIND ALL WELDS+DYE-PEN INSP	0	600	2000	39
1075 X-RAY ALL WELDS	2.3	0	0	2.3
1076 PERFORM LEAK CHECK+WGH+STORE	1	150	400	9.25
1080 RING:F/D:COMMON BULKHEAD				
1081 VERIFY MTL FOR 1 F/D Y RING	3.5	0	0	3.5
1082 FORM+INSP	0	140	260	6
1083 TRIM+CLEAN+AGE+INSP	0	40	140	2.7
1084 ANODIZE+WEIGH+STORE	0	40	80	1.8
1085 WELD SEG+STRAIGHTEN RING+INSP	0	400	800	18
1086 MILL RING FACE+INSP+STORE	0	250	500	11.25
1090 COMMON BULKHEAD AFT DOME				
1091 VERIFY MTL FOR C/B AFT DOME	0	0	0	0
1092 SCRIBE+SAW BLK TO REQ SHAPE	0	160	320	7.2
1093 SHEAR SPIN FORM+INSP	0	200	460	9.9
1094 CLEAN+ANNEAL+QUENCH+INSP	0	240	320	8.4
1095 SPIN FORM TO SHAPE+INSP	0	300	600	13.5
1096 CHEAN+ANNEAL+QUENCH+INSP	0	240	320	8.4
1097 FINAL FORM SPIN+STA TRIM+INSP	0	300	600	13.5
1098 CUT+TRIM C/C OPNG+DEBURR+INSP	0	80	260	5.1
1099 CLN+HEAT TREAT+AGE+INSP+STORE	0	300	540	12.6
1100 MASK+CHEM MILL+DEBURR+INSP	32	900	0	45.5
1110 CLEAN+ANODIZE+INSP	0	270	360	9.45

MANUFACTURING PROCESSES	MAT'L COST (K$)	Q.C. LABOR (M/HR)	MFG. LABOR (M/HR)	TOTAL COST (K$)
1111 WELD DOME TO RING+INSP	6.4	260	340	15.4
1112 WELD CENTER CAP TO DOME+INSP	2.8	130	200	7.75
1113 GRIND ALL WELDS+DYE-PEN INSP	0	600	2000	39
1114 X-RAY ALL WELDS	4.6	0	0	4.6
1115 PERFORM LEAK CHECK+WGH+STORE	1	150	400	9.25
2010 RING:A/D:COMMON BULKHEAD				
2011 VERIFY MTL FOR 1 A/D Y RING.	3.5	0	0	3.5
2012 FORM+INSP	0	140	260	6
2013 TRIM+CLEAN+AGE+INSP	0	40	140	2.7
2014 ANODIZE+WEIGH+STORE	0	40	80	1.8
2015 WELD SEG+STRAIGHTEN RING+INSP	0	400	800	18
2016 MILL RING FACE+INSP+STORE	0	250	500	11.25
2020 TANK CYLINDER				
2021 VERIFY MTL FOR 7 TANK SEG(S)	310	0	0	310
2022 MILL EDGES	65	280	560	77.6
2023 MILL WAFFLE PATTERN	325	280	560	337.6
2024 ULTRASONIC INSP	138.5	0	0	138.5
2025 MOVE SEG(S) TO A/A	0	70	140	3.15
2027 DRILL SPREADER BAR HOLES	0	140	280	6.3
2029 HEAT TREAT(ANNEAL)	0	0	140	2.1
2030 FORM 7 SKINS+CLN+AGE+INSP	0	980	2030	45.15
2031 ANODIZE+TRIM+WGH+INSTL S/B(S)	0	310	450	11.4
2041 WELD SEG(S)+INSP	22	1060	2120	69.7
2043 TRIM CYL+WELD RINGS	12.7	340	660	27.7
2044 X-RAY ALL WELDS+WEIGH+STORE	26	200	800	41
2050 RING TANK CYL				
2051 VERIFY MTL FOR 2 RINGS(CYL)	7.	0	0	7
2052 FORM 8 SEG(S)+INSP	0	280	520	12
2053 TRIM+AGE+INSP	0	80	280	5.4
2054 ANODIZE+WEIGH+STORE	0	80	160	3.6
2055 WELD SEG+STRTN RINGS+INSP	0	800	1600	36
2056 MILL RING FACE+INSP+WEIGH	0	450	900	20.25
2057 MOVE RINGS TO A/A	0	50	100	2.25
2060 FWD DOME				
2061 VERIFY MTL FOR FWD DOME	13	0	0	13
2062 SCRIBE+SAW BLK TO REQ SHAPE	0	160	320	7.2
2063 SHEAR SPIN FORM+INSP	0	200	460	9.9
2064 CLEAN+ANNEAL+QUENCH+INSP	0	240	320	8.4
2065 SPIN FORM TO SHAPE+INSP	0	300	600	13.5
2066 CLEAN+ANNEAL+QUENCH+INSP	0	240	320	8.4
2067 FINAL FORM SPIN+STA TRIM+INSP	0	300	600	13.5
2068 CUT+TRIM C/C OPNG+DEBURR+INSP	0	80	260	5.1
2069 CLN+HEAT TREAT+AGE+INSP+STORE	0	300	540	12.6
2070 MASK+CHEM MILL+DEBURR+INSP	78	900	0	91.5
2071 CLEAN+ANODIZE+INSP	0	180	270	6.75
2072 WEIGH+STORE	0	50	90	2.1
2073 WELD JAMB+INSP	2.8	130	180	7.45
2074 WELD STUDS+FITTINGS+INSP	2.2	190	230	8.5
2075 GRIND ALL WELDS+DYE-PEN INSP	0	600	2000	39
2076 PERFORM LEAK CHECK	1	100	300	7
2077 X-RAY ALL WELDS+WEIGH	3.	950	40	17.85
2078 LD ON TRNSPR+MOVE F/D TO A/A	0	60	120	2.7
	1369.7	39260	72930	3052.55
LABOR COST (K$)		(588.9)	(1093.95)	

SUMMARY OF RESULTS

	MAT'L COST (K$)	Q.C. LABOR (M/HR)	MFG. LABOR (M/HR)	PRE-MFG. LABOR (M/HR)	TOTAL COST (K$)
TOOLING					3395.7
FACILITIES					6972
PRE-MANUFACTURING					
NON-RECURRING COST				64540.	968.1
RECURRING COST				10000	150
MFG. PROCESSES	1369.7	39260	72930		3052.55
	1369.7	39260	72930	74540.	14538.4
LABOR IN (K$)		(588.9)	(1093.95)		

Table 5-10

Manufacturing Cost Analysis

MANUFACTURING COST ANALYSIS
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09/23/70

LINE: STATE-OF-THE-ART MANUFACTURING LINE (LINE 1)

STRUCTURE: PROPELLANT TANK STRUCTURE (ELEMENT 2)

PRODUCTION RATE: 20 PER YEAR

VARIATION FROM THE NOMINAL: NONE

TOTAL PROGRAM LENGTH: 5 YEARS

LABOR RATES-($/HR): PRE-MFG.- 15. ; Q.C.- 15. ; MFG.- 15.

PLANT NO. 1

TOOLING	UNIT COST (K$)	NO. UNITS	TOTAL COST (K$)
100 STRETCH PRESS	650	3	1950
101 STRETCH FORM DIE #1	30	2	60
102 STRETCH FORM DIE #2	30	1	30
110 HEAT TREAT OVEN (12'X12'X40'	200	2	400
111 QUENCH TANK (12'X12'X40')	50	1	50
120 DOME SEGMENT TRIM TOOL	20	1	20
121 DOME SEGMENT CUTTER	5	1	5
122 WORK STAND	1	2	2
130 DOME ROTATING TOOL	125	1	125
131 ETCH CLEANING TANK (25'X25'X12')	50	1	50
132 ETCH CLEANING TANK (12'X12'X40')	50	1	50
140 SPRAY BOOTH	20	1	20
141 NEOPRENE MASKANT SPRAY	2	1	2
142 MASKANT CUT STENCIL #1	0.5	5	2.5
143 MASKANT CUT STENCIL #2	0.5	5	2.5
144 MASKANT CUT STENCIL #3	0.5	5	2.5
145 MASKANT CUT STENCIL #4	0.5	5	2.5
150 CHEM MILL 12'X12'X12'	25	2	50
160 ANODIZE 12'X12'X40'	25	4	100
170 LOAD CELL #1	2	1	2
171 HOIST SPREADER BAR #1	0.8	4	3.2
172 HOIST SPREADER BAR #2	0.8	4	3.2
173 HOIST SPREADER BAR #3	0.8	2	1.6
180 MERIDIAN WELDER	100	3	300
181 CLAMP BAR	20	3	60
182 WELDING HEAD STAND	30	3	90
183 WELDING HEAD	10	3	30
184 STATION TRIMMER	10	3	30
185 XRAY UNIT	18	3	54
190 JAMB RING WELDER STAND	30	2	60
191 JAMB CLAMPS	2	2	4
192 JAMB RING/DOLLAR OPENING TRIMMER	5	2	10
193 JAMB RING/DOLLAR WELDER	7	2	14
194 XRAY	18	2	36
200 PICK UP POSITIONER	7	2	14
201 STUD WELDER HEAD	10	2	20
210 XRAY HOLDING FIXTURE	15	4	60
211 XRAY UNIT	18	4	72
220 SPREADER BAR #4 (HOIST)	0.8	4	3.2
221 LOAD CELL #2	2	2	4
230 TRANSPORT FIXTURE	4	6	24
240 DOME TO RING WELD FIXTURE	12	1	12
241 WELDING HEAD	18	1	18
242 XRAY UNIT	18	1	18
250 STRETCH PRESS	20	1	20
251 RING DIE #1	2	1	2
252 RING DIE #2	2	1	2
253 RING DIE #3	2	1	2
260 RING EXTRUSION CUTTER	0.5	1	0.5
270 RING WELD FIXTURE	20	1	20
271 RING WELD FIXTURE SET 1	1	1	1
272 RING WELD FIXTURE SET 2	1	1	1
273 WELDING HEAD	10	1	10
280 VERTICAL BORING MILL	350	1	350
281 LATHE FIXTURE #1	12	1	12
282 LATHE FIXTURE #2	12	1	12
283 LATHE FIXTURE #3	12	1	12
290 BONDING GANTRY	40	4	160
291 HEAT/PRESSURE DOME	80	4	320
292 VACUUM BAG	8	4	32
293 BLEEDER CLOTH	2	4	8
294 VACUUM PUMP	2	4	3
295 SONIC MEASURING DEVICE & AUTO. READOUT	25	4	100
300 COMMON BULKHEAD RING BUTT WELD FIXTURE	8	2	16
301 WELDING HEAD	18	2	36
310 COMMON BULK LATHE FIXTURE	12	1	12
311 RING CUTTING TOOL	1	1	1
320 SPREADER BARS (HOIST)	1	2	2
321 LOAD CELL	2	2	4
330 AMMONIA GAS PRESSURE TEST RIG	10	4	40
340 LOX TANK WELD FIXTURE	35	3	105
341 DRILL	1	3	3
342 DRILL JIGS	2	3	6
343 WELDER	18	3	54
350 SKIN MILL (10'X40')	500	1	500
PLANT 1 TOOLING COST (K$)			5718.7

PLANT NO.2

TOOLING	UNIT COST (K$)	NO. UNITS	TOTAL COST (K$)
360 DRILL TEMPLATE	0.5	4	2
361 POWER DRILL	1	4	4
370 BRAKE - 40'	150	1	150
380 SEGMENT TRIM FIXTURE	35	2	70
381 POWER CUTTER	5	2	10
390 SPREADER BARS	0.2	28	5.6
391 LONGITUDINAL WELD FIXTURE	45	2	90
392 WELDER HEAD	18	2	36
400 END TRIM/RING WELD DOLLY	75	2	150
401 WELD FIXTURE	5	2	10
402 WELDER HEAD	18	2	36
410 XRAY	18	1	18
420 HOIST SPREADER BAR	1.5	4	6
421 LOAD CELL	2	2	4
430 TANK ASSEM TOWER	200	6	1200
431 HEAT BLANKET	12	6	72
432 WELDER HEAD	18	6	108
433 XRAY	18	6	108
434 HOISTING YOKE & CRANE	50	6	300
440 HYDROSTATIC TEST EQUIP	100	6	600
441 DEGREASER	80	6	480
450 TANK DOLLY	40	6	240
451 HOIST YOKE	10	6	60
452 LOAD CELL	2	6	12
460 WELD GRINDER(PORTABLE)	1	6	6
PLANT 2 TOOLING COST (K$)			3777.6
TOTAL TOOLING COST (K$)			9496.3

FACILITIES	TOTAL COST (K$)
500 PLANT # 1-MANUFACTURING	6925
600 PLANT #2-ASSEMBLY	15908
	22833

TRANSPORTATION	
700 TRANSPORT 100 MILES FROM PLANT 1 TO PLANT 2	
701 NON-RECURRING COST	72.3
702 RECURRING COST	390
	462.3

NEAR-TERM PRE-MANUFACTURING OPERATIONS

ITEM	M/HRS	TOTAL COST (K$)
NON-RECURRING COSTS		
800 REVIEW PROGRAM DIRECTIVES	700.	10.5
810 MFG. PRELIMINARY SCHEDULES	700.	10.5
820 PRODUCIBILITY STUDIES	9380.	140.7
830 IDENTIFY/ORDER LONG LEAD ITEMS	1890.	28.35
840 ACCUMULATE/REVIEW ENGR & QC DOCUMENT.	1890.	28.35
850 DEVELOP SUB-ASSEMBLY & PARTS SCHEDULE	9380.	140.7
860 MFG. PLANNING OPERATIONS	14000.	210
870 DESIGN/PROCURE TOOLING	22400.	336
880 VENDOR EVALUATION & SELECTION	4200.	63
NON-RECURRING TOTALS	64540.	968.1
RECURRING COSTS		
900 EXPEDITE IN-HOUSE/PURCHASE PARTS	80000.	1200
910 REVIEW PROGRESS WITH PROGRAM OFFICE	20000.	300
RECURRING TOTALS	100000	1500
TOTAL RECURRING AND NON-RECURRING PRE-MFG. COSTS=		2468.1

MANUFACTURING PROCESSES	MAT'L COST (K$)	Q.C. LABOR (M/HR)	MFG. LABOR (M/HR)	PLANT NO.	TOTAL COST (K$)
1000 TANK ASSEMBLY					
1001 UNPACK FWD DOME+INSP	0	2000	1000	2	45
1002 UNPACK LOX TANK+INSP	0	4000	1000	2	75
1003 MOVE F/D+L/T TO ASSY TOWER	0	0	2000	2	30
1004 WELD CYL TO L/T(INTER)+INSP	62.	11200	17200	2	488
1005 WELD CYL TO L/T(EXTER)+INSP	62.	5200	5200	2	218
1006 WELD CYL TO F/D(INTER)+INSP	62.	11200	14200	2	443
1007 WELD CYL TO F/D(EXTER)+INSP	62.	10200	10200	2	368
1008 HYDROSTATIC TEST	0	20000	40000	2	900
1009 DEGREASE	0	5000	10000	2	225
1010 WEIGH+STORE	0	2000	12500	2	217.5
1020 LOX TANK ASSY					
1021 MATE C/B+A/D:SEAL WELD+INSP	198.	15600	16000	1	672
1022 X-RAY ALL WELDS+WEIGH	28.	2000	4000	1	118
1023 BOX+PKG: SHIP TO A/F	0	500	1000	1	22.5
1030 AFT DOME ASSY					
1031 VERIFY MTL FOR A/D SEG(S)	350	0	0	1	350
1032 FORM 9 SEG(S)+INSP	0	10200	18000	1	423
1033 ROUGH TRIM+CLN+AGE+INSP+STORE	0	1800	8900	1	160.5
1034 MASK+CHEM MILL+DEBURR+INSP	780.	9000	0	1	915
1035 ANODIZE+TRIM+INSP	0	1800	2700	1	67.5
1036 WEIGH SEG(S)+STORE	0	500	900	1	21
1037 WELD SEG(S)+STATION TRIM+INSP	138	18400	12400	1	600
1038 WELD JAMB+INSP	28.	1300	1800	1	74.5
1039 WELD STUDS+FITTINGS+INSP	22	1900	2300	1	85
1040 GRIND ALL WELDS+DYE-PEN INSP	0	6000	20000	1	390
1041 PERFORM LEAK CHECK	10	1000	3000	1	70
1042 X-RAY ALL DOME WELDS+WEIGH	30.	9500	400	1	178.5
1043 TRANSPORT TO L/T A/A	0	500	1000	1	22.5
1050 COMMON BULKHEAD ASSY					
1051 ETCH CLEAN AFT DOME	20	1500	3000	1	87.5
1052 ETCH CLEAN FWD DOME	20	1500	3000	1	87.5
1053 FIT+BOND HONEYCOMB+INSP	380	40000	160000	1	3380
1054 BUTT WELD Y RINGS+LK CK+INSP	64.	2200	4200	1	160
1055 MACHINE RING BUTT WELDS	0	2000	8000	1	150
1056 X-RAY WELD+U/I DOME+WGH+STORE	424.	3000	1000	1	484
1060 COMMON BULKHEAD F/D					
1061 VERIFY MTL FOR C/B F/D	160	0	0	1	160
1062 FORM 9 SEG(S)+INSP	0	10200	18000	1	423
1063 ROUGH TRIM+CLN+AGE+INSP+STORE	0	1800	8900	1	160.5
1064 MASK+CHEM MILL+DEBURR+INSP	380	9000	0	1	515
1065 ANODIZE+TRIM+INSP	0	2700	3600	1	94.5
1066 WEIGH SEG(S)+STORE	0	500	900	1	21
1067 WELD SEG(S)+STATION TRIM+INSP	138	18000	12400	1	594
1068 WELD DOME TO RING+INSP	64.	2600	3400	1	154
1069 WELD CENTER CAP TO DOME+INSP	28.	1300	2000	1	77.5
1070 GRIND ALL WELDS+DYE-PEN INSP	0	6000	20000	1	390
1071 X-RAY ALL WELDS	46.	0	0	1	46
1072 PERFORM LEAK CHECK+WGH+STORE	10	1500	4000	1	92.5
1080 RING:F/D:COMMON BULKHEAD					
1081 VERIFY MTL FOR 1 F/D Y RING	35	0	0	1	35
1082 FORM+INSP	0	1400	2600	1	60
1083 TRIM+CLN+AGE+INSP	0	400	1400	1	27
1084 ANODIZE+WEIGH+STORE	0	400	800	1	18
1085 WELD SEG+STRAIGHTEN RING+INSP	0	4000	8000	1	180
1086 MILL RING FACE+INSP+STORE	0	2500	5000	1	112.5
1090 COMMON BULKHEAD AFT DOME					
1091 VERIFY MTL FOR C/B AFT DOME	170.	0	0	1	170
1092 FORM 9 SEG(S)+INSP	0	10200	18000	1	423
1093 ROUGH TRIM+CLN+AGE+INSP+STORE	0	1800	8900	1	160.5
1094 MASK+CHEM MILL+DEBURR+INSP	320	9000	0	1	455
1095 ANODIZE+TRIM+INSP	0	2700	3600	1	94.5
1096 WEIGH SEG(S)+STORE	0	500	900	1	21
1097 WELD SEG(S)+STATION TRIM+INSP	138	18000	12400	1	594
1098 WELD DOME TO RING+INSP	64.	2600	3400	1	154
1099 WELD CENTER CAP TO DOME+INSP	28.	1300	2000	1	77.5
1100 GRIND ALL WELDS+DYE-PEN INSP	0	6000	20000	1	390
1101 X-RAY ALL WELDS	46.	0	0	1	46
1102 PERFORM LEAK CHECK+WGH+STORE	10	1500	4000	1	92.5
2010 RING:A/D:COMMON BULKHEAD					
2011 VERIFY MTL FOR 1 A/D Y RING	35	0	0	1	35
2012 FORM+INSP	0	1400	2600	1	60
2013 TRIM+CLEAN+AGE+INSP	0	400	1400	1	27
2014 ANODIZE+WEIGH+STORE	0	400	800	1	18
2015 WELD SEG+STRAIGHTEN RING+INSP	0	4000	8000	1	180
2016 MILL RING FACE+INSP+STORE	0	2500	5000	1	112.5
2020 TANK CYLINDER					
2021 VERIFY MTL FOR 7 TANK SEG(S)	3100	0	0	1	3100
2022 MILL EDGE	650	2800	5600	1	776
2023 MILL WAFFLE PATTERN	3250	2800	5600	1	3376
2024 ULTRASONIC INSP	1385.	0	0	1	1385
2025 BOX+PKG:SHIP TO A/F	0	700	1400	1	31.5
2026 UNPACK+TRANSPORT TO WORK AREA	0	700	1400	2	31.5
2027 DRILL SPREADER BAR HOLES	0	1400	2800	2	63
2029 HEAT TREAT(ANNEAL)	0	0	1400	2	21
2030 FORM 7 SKINS+CLN+AGE+INSP	0	9800	20300	2	451.5
2031 ANODIZE+TRIM+WGH+INSTL S/B(S)	0	3100	4500	2	114
2041 WELD SEG(S)+INSP	220.	10600	21200	2	697
2042 UNPACK 2 RINGS	0	500	1000	2	22.5
2043 TRIM CYL+WELD RINGS	127	3400	6600	2	277
2044 X-RAY ALL WELDS+WEIGH+STORE	260	2000	8000	2	410
2050 RING:TANK CYL					
2051 VERIFY MTL FOR 2 RINGS(CYL)	70	0	0	1	70
2052 FORM 8 SEG(S)+INSP	0	2800	5200	1	120
2053 TRIM+AGE+INSP	0	800	2800	1	54
2054 ANODIZE+WEIGH+STORE	0	800	1600	1	36
2055 WELD SEG+STRTN RINGS+INSP	0	8000	16000	1	360
2056 MILL RING FACE+INSP+WEIGH	0	4500	9000	1	202.5
2057 BOX+PKG RINGS:SHIP TO A/F	0	500	1000	1	22.5
2060 FWD DOME					
2061 VERIFY MTL FOR FWD DOME SEG	180	0	0	1	180
2062 FORM 9 SEG(S)+INSP	0	10200	18000	1	423
2063 ROUGH TRIM+CLN+AGE+INSP+STORE	0	1800	8900	1	160.5
2064 MASK+CHEM MILL+DEBURR+INSP	300	9000	0	1	435
2065 ANODIZE+TRIM+INSP	0	1800	2700	1	67.5
2066 WEIGH SEG(S)+STORE	0	500	900	1	21
2067 WELD SEG(S)+STATION TRIM+INSP	138	18400	12400	1	600
2068 WELD JAMB+INSP	28.	1300	1800	1	74.5
2069 WELD STUDS+FITTINGS+INSP	22	1900	2300	1	85
2070 GRIND ALL WELDS+DYE-PEN INSP	0	6000	20000	1	390
2071 PERFORM LEAK CHECK	10	1000	3000	1	70
2072 X-RAY ALL DOME WELDS+WEIGH	30.	9500	400	1	178.5
2073 BOX+PKG F/D:SHIP TO A/F	0	500	1000	1	22.5

	PLANT 1	PLANT 2	TOTAL
MANUFACTURING PROCESSES 5 YR COST-(K$)	27031	5097	32128
MATERIAL COST-(K$)	13327	855	14182
QUALITY CONTROL LABOR-(M/HRS)	340400	102300	442700
-(K$)	5106	1534.5	6640.5
MANUFACTURING LABOR-(M/HRS)	573200	180500	753700
-(K$)	8598	2707.5	11305.5

SUMMARY OF RESULTS

	MAT'L COST (K$)	Q.C. LABOR (M/HR)	MFG. LABOR (M/HR)	PRE-MFG. LABOR (M/HR)	TOTAL COST (K$)
TOOLING					9496.3
FACILITIES					22833
TRANSPORTATION					
NON-RECURRING COST					72.3
RECURRING COST					390
PRE-MANUFACTURING					
NON-RECURRING COST				64540.	968.1
RECURRING COST				100000	1500
MFG. PROCESSES	14182	442700	753700		32128
	14182	442700	753700	164540.	67387.7
LABOR IN (K$)		(6640.5)	(11305.5)		

	PLANT 1	PLANT 2	TOTAL
MANUFACTURING PROCESSES 5 YR COST-(K$)	27031	5097	32128
MATERIAL COST-(K$)	13327	855	14182
QUALITY CONTROL LABOR-(M/HRS)	340400	102300	442700
MANUFACTURING LABOR-(M/HRS)	573200	180500	753700
FACILITIES: MFG. & ASSEMBLY-(K$)	6925	15908	22833
TOOLING-(K$)	5718.7	3777.6	9496.3
TRANSPORTATION-(K$)	FROM	TO	462.3

5.1.2 SUPPORT FRUSTUM STRUCTURE, ELEMENT NO. 1

5.1.2.1 General

The frustum adapter structure, illustrated in Figure 2-2, is representative of the unpressurized, mechanically fastened structures that are widely used in the aerospace industry. The particular model selected for this study is 50.5 inches in diameter at the largest part and tapers to an upper ring 45.8 inches in diameter.

At the upper surface of the frustum, an aluminum honeycomb bulkhead is attached to carry the payload loads to the frustum and thereby to the vehicle's outer skin. The structure is of a riveted, stiffened skin construction, consisting of:

a. Four conically formed skins.
b. Two rings (upper and lower).
c. Sixteen longerons.
d. One aluminum honeycomb bulkhead.

The principal design criterion is the ability to withstand high loads with minimum deflection of the bulkhead. Minimum weight is important but secondary to the above criterion. The current method of fabrication is to form the rings, skins, and longerons and assemble by riveting. The upper bulkhead is prefabricated and attached by rivets in a similar manner.

A typical procedure in current practice is that the aluminum bulkhead and lower rings are fabricated by subcontractors. In the use of the aluminum honeycomb bulkhead, the necessary tooling is supplied by the prime contractor (General Electric), in addition to paying a cost of approximately $10,000 per bulkhead. A significant part of this $10,000 is directly attributable to numerous fastener installations which are inserted and bonded in place after the initial construction of the honeycomb is complete.

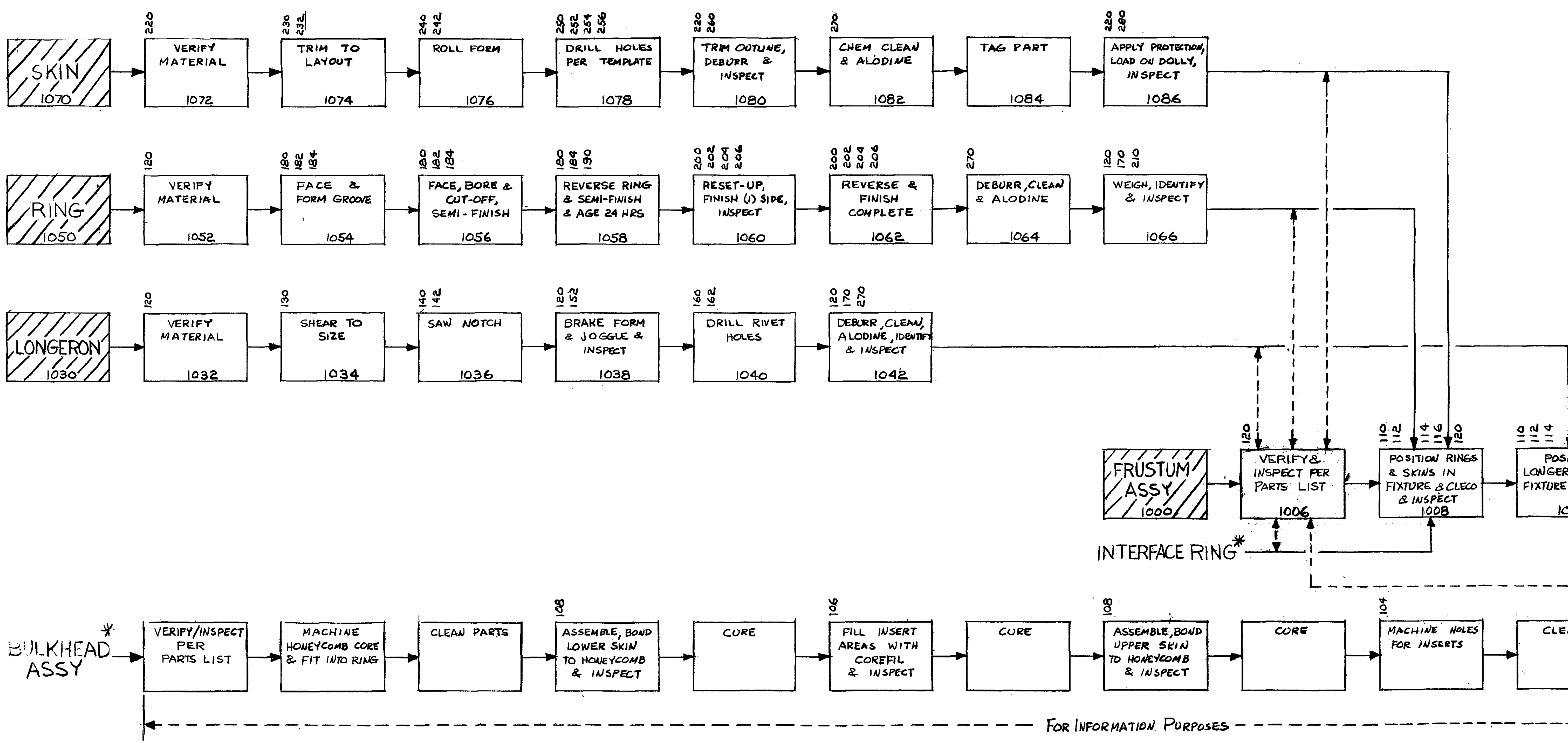
The details of the manufacturing processes are shown in Figure 5-3 for the support frustum. The processes and tooling indicated in this figure are described in the following sections.

5.1.2.2 Manufacturing Processes, Methods and Tooling

The manufacturing processes and materials used in definition of the state-of-the-art line (Line 1) are similar to those used on the Mark XII support frustum. In some cases, the planning was changed to illustrate possible variations in method for study purposes.

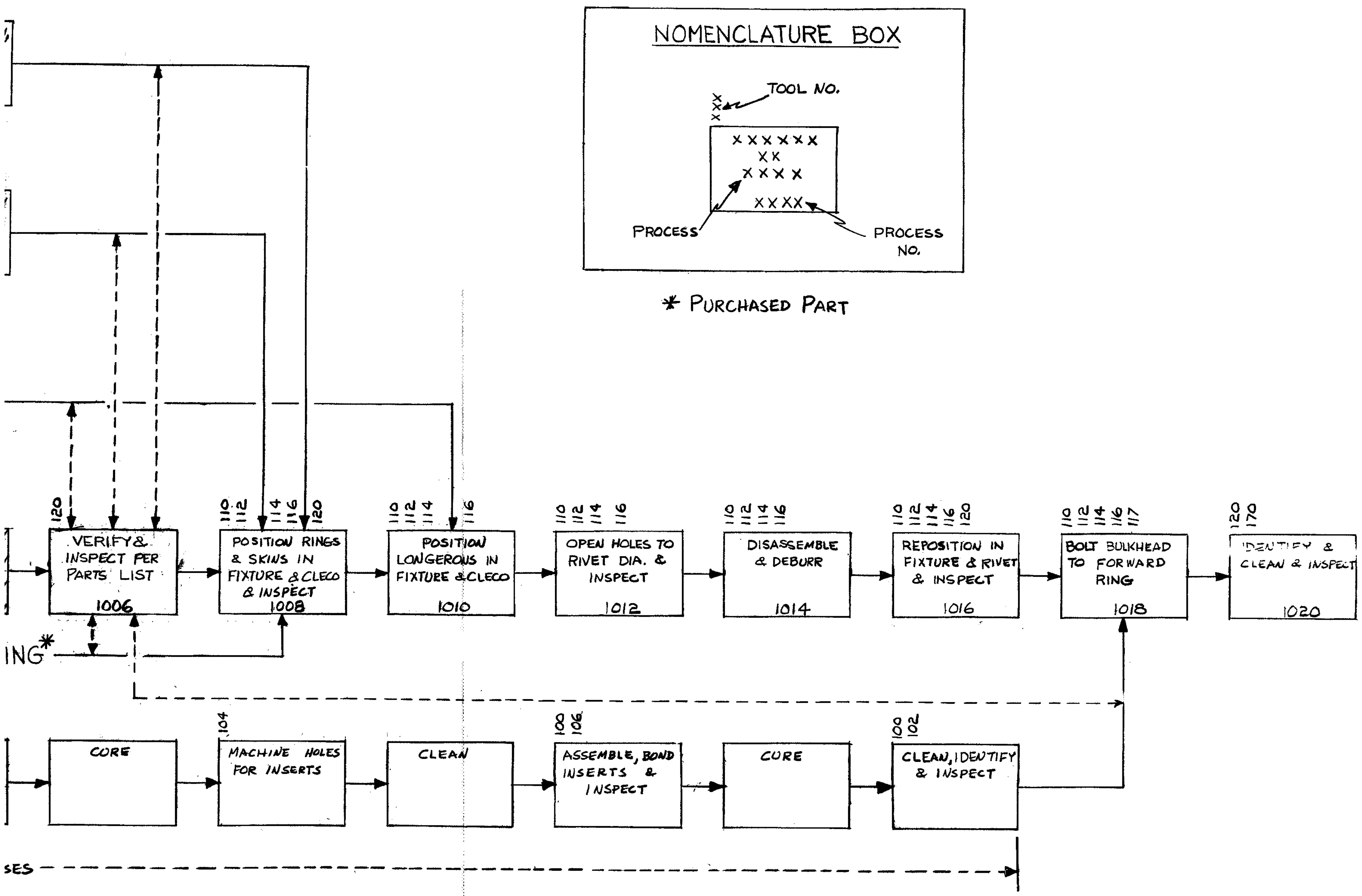
The computer printout of the manufacturing processes, with numbered steps corresponding to the flow chart in Figure 5-3, is shown in Tables 5-11 and 5-12. Although the honeycomb bulkhead is shown as a procured item, the detailed steps are illustrated in Figure 5-3 for further clarity of manufacturing steps.

The costs for materials and man-hours for quality control, manufacturing, assembly and test are tabulated in Tables 5-11 and 5-12. The lot size assumed for the calculations is that enough parts are made in one batch for one assembly. This necessitates set-up and completion of all operations for one assembly before continuing with the next operations for each of the tools. With the exception of the assembly fixtures, the rates of 2 per year and 20 per year require far less than full utilization of tools and fixtures (Tables 5-11 and 5-12). Production of greater than 20 per year could readily be accommodated with only limited increase in factory and tooling requirements. Unlike structural element 2 (the propellant tank) where rates are limited by the large size and usage of forming tools, the support frustum can be readily accommodated by a modest aerospace fabrication shop. In fact, economics indicate the advantage of multiple use of existing tools, in between operations for the 2 per year or 20 per year of this study. However, the costs of this study were determined assuming that charges include only those hours for the actual fabrication and do not incur additional costs for personnel stand-by or retention of certain key skills or experiences.



SKIN 1070
VERIFY MATERIAL 1072
TRIM TO LAYOUT 1074
ROLL FORM 1076
DRILL HOLES PER TEMPLATE 1078
TRIM OUTLINE, DEBURR & INSPECT 1080
CHEM CLEAN & ALODINE 1082
TAG PART 1084
APPLY PROTECTION, LOAD ON DOLLY, INSPECT 1086
RING 1050
VERIFY MATERIAL 1052
FACE & FORM GROOVE 1054
FACE, BORE & CUT-OFF, SEMI-FINISH 1056
REVERSE RING & SEMI-FINISH & AGE 24 HRS 1058
RESET-UP, FINISH (1) SIDE, INSPECT 1060
REVERSE & FINISH COMPLETE 1062
DEBURR, CLEAN & ALODINE 1064
WEIGH, IDENTIFY & INSPECT 1066
LONGERON 1030
VERIFY MATERIAL 1032
SHEAR TO SIZE 1034
SAW NOTCH 1036
BRAKE FORM & JOGGLE & INSPECT 1038
DRILL RIVET HOLES 1040
DEBURR, CLEAN, ALODINE, IDENTIFY & INSPECT 1042
FRUSTUM ASSY 1000
VERIFY & INSPECT PER PARTS LIST 1006
POSITION RINGS & SKINS IN FIXTURE & CLECO & INSPECT 1008
POSITI LONGERON FIXTURE & 1010
INTERFACE RING*
BULKHEAD ASSY*
VERIFY/INSPECT PER PARTS LIST
MACHINE HONEYCOMB CORE & FIT INTO RING
CLEAN PARTS
ASSEMBLE, BOND LOWER SKIN TO HONEYCOMB & INSPECT
CORE
FILL INSERT AREAS WITH COREFIL & INSPECT
CORE
ASSEMBLE, BOND UPPER SKIN TO HONEYCOMB & INSPECT
CORE
MACHINE HOLES FOR INSERTS
CLEAN
FOR INFORMATION PURPOSES
220
230 232
240 242
250 252 254 256
220 260
270
220 280
120
180 182 184
180 182 184
180 184 190
200 202 204 206
200 202 204 206
270
120 170 210
120
130
140 142
120 152
160 162
120 170 270
120
110 112 114 116 120
110 112 114
108
106
108
104

FOLD-OUT # 1



FOLD-OUT #2

Figure 5-3. Typical Manufacturing Flow Diagram—Support Frustum Structure

Table 5-11

Manufacturing Cost Analysis, 2 Per Year, Line 1, Element 1

MANUFACTURING CØST ANALYSIS
****

09/24/70

LINE: STATE-ØF-THE-ART MANUFACTURING LINE (LINE 1)

STRUCTURE: SUPPØRT FRUSTUM STRUCTURE (ELEMENT 1)

PRØDUCTIØN RATE: 2 PER YEAR

VARIATIØN FRØM THE NØMINAL: NØNE

TØTAL PRØGRAM LENGTH: 5 YEARS

LABØR RATES-($/HR): PRE-MFG.- 15. ; Q.C.- 15. ; MFG.- 15.

TØØLING	UNIT CØST (K$)	NØ. UNITS	TØTAL CØST (K$)
100 CØNTRØL MASTER FIXTURES	5	2	10
102 MASTER DRILL FIXTURES	5	2	10
104 DRILL FIXTURES	5	2	10
106 INSERT LØCATING FIXTURES	2	2	4
108 BULKHEAD ASSEMBLY FIXTURES	3	2	6
110 ASSEMBLY FIXTURE	3	1	3
112 CLECØS	0.0005	200	0.1
114 DRILL	0.05	1	0.05
116 WØRK STAND	0.1	1	0.1
117 TØRQUE TØØLS & WRENCH SET	0.15	1	0.15
120 INSPECTIØN STATIØN	0.5	1	0.5
130 SHEAR	18	1	18
140 BAND SAW	0.4	1	0.4
142 APPLIED TEMPLATE	0.065	1	0.065
152 BRAKE	12	1	12
160 HAND DRILL	0.05	1	0.05
162 TEMPLATE	0.08	1	0.08
170 METAL TAG STAMP	0.01	1	0.01
180 BØRING MILL	40	1	40
182 HØLDING FIXTURE	0.3	1	0.3
184 CUTTING TØØLS	0.04	1	0.04
190 RING HØLDING FIXTURE	0.3	1	0.3
200 MICRØMETER	0.05	1	0.05
202 HEIGHT GAGE	0.05	1	0.05
204 INDICATØR	0.05	1	0.05
206 RØUGHNESS GAGE	0.04	1	0.04
210 WEIGH SCALE	0.5	1	0.5
220 SKIN INSPECTIØN STATIØN	0.3	1	0.3
230 BENCH	0.1	1	0.1
232 LAYØUT TEMPLATE	0.065	1	0.065
240 RØLL FØRMER	8	1	8
242 CØNTØUR TEMPLATE	0.065	1	0.065
250 WØRK STAND	0.1	1	0.1
252 APPLIED TEMPLATE	0.065	1	0.065
254 SKIN HAND DRILL	0.05	1	0.05
256 PUNCHES	0.02	1	0.02
260 TRIM TEMPLATE	0.065	1	0.065
270 CLEAN & ALØDINE TANKS	10	1	10
280 DØLLY	0.2	1	0.2
TØTAL TØØLING CØST (K$)			134.865

MANUFACTURING PRØCESSES	MAT'L CØST (K$)	Q.C. LABØR (M/HR)	MFG. LABØR (M/HR)	TØTAL CØST (K$)
1000 FRUSTUM ASSEMBLY				
1002 PURCHASE 1 RING	10	0	0	10
1004 PURCHASE 1 BULKHEAD	100	0	0	100
1006 VERIFY,INSP. PARTS	0	60	0	0.9
1008 CLECØ RING&SKIN IN FIXT,INSP	0	10	320	4.95
1010 PØS'N LØNGERØNS IN FIXT,CLECØ	0	0	240	3.6
1012 ØPEN HØLES TØ RIVET DIA, INSP	0	0	80	1.2
1014 DISASSEMBLE & DEBURR	0	0	200	3
1016 REPØSITIØN IN FIXT,RIVET,INSP	0.25	40	320	5.65
1018 BØLT BULKHEAD TØ FWD RING	0	0	20	0.3
1020 IDENTIFY, CLEAN, INSP	0	45	20	0.975
1030 LØNGERØN				
1032 VERIFY MATERIAL	0.16	16	0	0.4
1034 SHEAR TØ SIZE	0	0	16	0.24
1036 SAW NØTCH	0	0	32	0.48
1038 BRAKE FØRM,JØGGLE,INSPECT	0	16	32	0.72
1040 DRILL RIVET HØLES	0	0	32	0.48
1042 DEBURR,CLEAN,ALØDINE,IDENT,INSP	0	16	32	0.72
1050 RING				
1052 VERIFY MATERIAL	0.3	30	0	0.75
1054 FACE & FØRM GRØØVE	0	0	32	0.48
1056 FACE,BØRE,CUT ØFF,SEMI-FINISH	0	0	85	1.275
1058 REVERSE RING,SEMI-FINISH,AGE	0	0	60	0.9
1060 RE-SETUP,FINISH 1 SIDE, INSP	0	10	23	0.495
1062 REVERSE & FINISH CØMPLETE,INSP	0	20	60	1.2
1064 DEBURR,CLEAN , ALØDINE	0.1	0	36	0.64
1066 WEIGH, IDENTIFY, INSPECT	0	10	10	0.3
1070 SKIN				
1072 VERIFY MATERIAL	0.6	8	0	0.72
1074 TRIM TØ LAYØUT	0	0	20	0.3
1076 RØLL FØRM	0	0	24	0.36
1078 DRILL HØLES PER TEMPLATE	0	0	52	0.78
1080 TRIM ØUTLINE,DEBURR,INSP	0	12	68	1.2
1082 CHEM CLEAN & ALØDINE	0.6	0	12	0.78
1084 TAG PART	0	0	8	0.12
1086 APPLY PRØTECT,LØAD ØN DØLY,INSP	0.2	8	8	0.44
	112.21	301	1842	144.355
LABØR CØST (K$)		(4.515)	(27.63)	

FACILITIES	TØTAL CØST (K$)
500 CØNSØLIDATED MANUFACTURING & ASSEMBLY PLANT	620

NEAR-TERM PRE-MANUFACTURING ØPERATIØNS

NØN-RECURRING CØSTS

ITEM	M/HRS	TØTAL CØST (K$)
800 REVIEW PRØGRAM DIRECTIVES	700.	10.5
810 MFG. PRELIMINARY SCHEDULES	420.	6.3
820 PRØDUCIBILITY STUDIES	700.	10.5
830 IDENTIFY/ØRDER LØNG LEAD ITEMS	500.	7.5
840 ACCUMULATE/REVIEW ENGR & QC DØCUMENT.	1120.	16.8
850 DEVELØP SUB-ASSEMBLY & PARTS SCHEDULE	528.	7.92
860 MFG. PLANNING ØPERATIØNS	3200.	48
870 DESIGN/PRØCURE TØØLING	1400.	21
880 VENDØR EVALUATIØN & SELECTIØN	1120.	16.8
NØN-RECURRING TØTALS	9688	145.32

RECURRING CØSTS

ITEM	M/HRS	TØTAL CØST (K$)
900 EXPEDITE IN-HØUSE/PURCHASE PARTS	2750.	41.25
910 REVIEW PRØGRESS WITH PRØGRAM ØFFICE	550.	8.25
RECURRING TØTALS	3300	49.5

TØTAL RECURRING AND NØN-RECURRING PRE-MFG. CØSTS= 194.82

SUMMARY ØF RESULTS

	MAT'L CØST (K$)	Q.C. LABØR (M/HR)	MFG. LABØR (M/HR)	PRE-MFG. LABØR (M/HR)	TØTAL CØST (K$)
TØØLING					134.865
FACILITIES					620
PRE-MANUFACTURING					
NØN-RECURRING CØST				9688	145.32
RECURRING CØST				3300	49.5
MFG. PRØCESSES	112.21	301	1842		144.355
	112.21	301	1842	12988	1094.04
LABØR IN (K$)		(4.515)	(27.63)		

Table 5-12

Manufacturing Cost Analysis, 20 Per Year, Line 1, Element 1

MANUFACTURING COST ANALYSIS
****

09/25/70

LINE: STATE-OF-THE-ART MANUFACTURING LINE (LINE 1)

STRUCTURE: SUPPORT FRUSTUM STRUCTURE (ELEMENT 1)

PRODUCTION RATE: 20 PER YEAR

VARIATION FROM THE NOMINAL: NONE

TOTAL PROGRAM LENGTH: 5 YEARS

LABOR RATES-($/HR): PRE-MFG.- 15. ; O.C.- 15. ; MFG.- 15.

TOOLING	UNIT COST (K$)	NO. UNITS	TOTAL COST (K$)
100 CONTROL MASTER FIXTURES	5	2	10
102 MASTER DRILL FIXTURES	5	2	10
104 DRILL FIXTURES	5	2	10
106 INSERT LOCATING FIXTURES	2	2	4
108 BULKHEAD ASSEMBLY FIXTURES	3	2	6
110 ASSEMBLY FIXTURE	3	1	3
112 CLECOS	0.0005	2000	1
114 DRILL	0.05	1	0.05
116 WORK STAND	0.1	1	0.1
117 TORQUE TOOLS & WRENCH SET	0.15	1	0.15
140 BAND SAW	0.4	1	0.4
142 APPLIED TEMPLATE	0.065	1	0.065
150 MECH. PRESS	2	1	2
160 HAND DRILL	0.05	1	0.05
162 TEMPLATE	0.08	1	0.08
170 METAL TAG STAMP	0.01	1	0.01
180 BORING MILL	40	1	40
182 HOLDING FIXTURE	0.3	1	0.3
184 CUTTING TOOLS	0.04	1	0.04
190 RING HOLDING FIXTURE	0.3	1	0.3
200 MICROMETER	0.05	1	0.05
202 HEIGHT GAGE	0.05	1	0.05
204 INDICATOR	0.05	1	0.05
206 ROUGHNESS GAGE	0.04	1	0.04
210 WEIGH SCALE	0.5	1	0.5
220 SKIN INSPECTION STATION	0.3	1	0.3
230 BENCH	0.1	1	0.1
232 LAYOUT TEMPLATE	0.065	1	0.065
240 ROLL FORMER	8	1	8
242 CONTOUR TEMPLATE	0.065	1	0.065
250 WORK STAND	0.1	1	0.1
252 APPLIED TEMPLATE	0.065	1	0.065
254 SKIN HAND DRILL	0.05	1	0.05
256 PUNCHES	0.02	1	0.02
260 TRIM TEMPLATE	0.065	1	0.065
270 CLEAN & ALODINE TANKS	10	1	10
280 DOLLY	0.2	1	0.2
TOTAL TOOLING COST (K$)			107.265

MANUFACTURING PROCESSES	MAT'L COST (K$)	O.C. LABOR (M/HR)	MFG. LABOR (M/HR)	TOTAL COST (K$)
1000 FRUSTUM ASSEMBLY				
1002 PURCHASE 1 RING	75	0	0	75
1004 PURCHASE 1 BULKHEAD	400	0	0	400
1006 VERIFY, INSP. PARTS	0	600	0	9
1008 CLECO RING&SKIN IN FIXT, INSP	0	100	3200	49.5
1010 POS'N LONGERONS IN FIXT, CLECO	0	0	2400	36
1012 OPEN HOLES TO RIVET DIA, INSP	0	0	800	12
1014 DISASSEMBLE & DEBURR	0	0	2000	30
1016 REPOSITION IN FIXT, RIVET, INSP	2.5	400	3200	56.5
1018 BOLT BULKHEAD TO FWD RING	0	0	200	3
1020 IDENTIFY, CLEAN, INSP	0	450	200	9.75
1030 LONGERON				
1032 VERIFY MATERIAL	1.6	160	0	4
1034 SAW TO LENGTH	0	0	160	2.4
1036 SCRIBE & SAW NOTCH	0	0	320	4.8
1038 JOGGLE, INSPECT	0	160	160	4.8
1040 DRILL RIVET HOLES	0	0	320	4.8
1042 DEBURR, CLEAN, ALODINE, IDENT, INSP	0	160	320	7.2
1050 RING				
1052 VERIFY MATERIAL	3.	300	0	7.5
1054 FACE & FORM GROOVE	0	0	320	4.8
1056 FACE, BORE, CUT OFF, SEMI-FINISH	0	0	850	12.75
1058 REVERSE RING, SEMI-FINISH, AGE	0	0	600	9
1060 RE-SETUP, FINISH 1 SIDE, INSP	0	100	230	4.95
1062 REVERSE & FINISH COMPLETE, INSP	0	200	600	12
1064 DEBURR, CLEAN , ALODINE	1.	0	360	6.4
1066 WEIGH, IDENTIFY, INSPECT	0	100	100	3
1070 SKIN				
1072 VERIFY MATERIAL	6.	80	0	7.2
1074 TRIM TO LAYOUT	0	0	200	3
1076 ROLL FORM	0	0	240	3.6
1078 DRILL HOLES PER TEMPLATE	0	0	520	7.8
1080 TRIM OUTLINE, DEBURR, INSP	0	120	680	12
1082 CHEM CLEAN & ALODINE	6.	0	120	7.8
1084 TAG PART	0	0	80	1.2
1086 APPLY PROTECT, LOAD ON DOLY, INSP	2.	80	80	4.4
	497.1	3010	18260	816.15
LABOR COST (K$)		(45.15)	(273.9)	

FACILITIES	TOTAL COST (K$)
500 CONSOLIDATED MANUFACTURING & ASSEMBLY PLANT	620

NEAR-TERM PRE-MANUFACTURING OPERATIONS

NON-RECURRING COSTS

ITEM	M/HRS	TOTAL COST (K$)
800 REVIEW PROGRAM DIRECTIVES	700.	10.5
810 MFG. PRELIMINARY SCHEDULES	420.	6.3
820 PRODUCIBILITY STUDIES	700.	10.5
830 IDENTIFY/ORDER LONG LEAD ITEMS	500.	7.5
840 ACCUMULATE/REVIEW ENGR & QC DOCUMENT.	1120.	16.8
850 DEVELOP SUB-ASSEMBLY & PARTS SCHEDULE	528.	7.92
860 MFG. PLANNING OPERATIONS	3200.	48
870 DESIGN/PROCURE TOOLING	1400.	21
880 VENDOR EVALUATION & SELECTION	1120.	16.8
NON-RECURRING TOTALS	9688	145.32

RECURRING COSTS

ITEM	M/HRS	TOTAL COST (K$)
900 EXPEDITE IN-HOUSE/PURCHASE PARTS	27500.	412.5
910 REVIEW PROGRESS WITH PROGRAM OFFICE	5500.	82.5
RECURRING TOTALS	33000	495

TOTAL RECURRING AND NON-RECURRING PRE-MFG. COSTS= 640.32

SUMMARY OF RESULTS

	MAT'L COST (K$)	O.C. LABOR (M/HR)	MFG. LABOR (M/HR)	PRE-MFG. LABOR (M/HR)	TOTAL COST (K$)
TOOLING					107.265
FACILITIES					620
PRE-MANUFACTURING					
NON-RECURRING COST				9688	145.32
RECURRING COST				33000	495
MFG. PROCESSES	497.1	3010	18260		816.15
	497.1	3010	18260	42688	2183.74
LABOR IN (K$)		(45.15)	(273.9)		

5.1.2.3 Facilities (Buildings)

The buildings and grounds necessary to produce the support frustum structure were laid out as an independent factory, in order to properly appraise the appropriate costs for manufacturing. The buildings and layout of facilities are shown in Figures 5-4 and 5-5 and and have resulted in the costs calculated below and summarized in Tables 5-11 and 5-12.

• Building—20,000 square feet at $25* per square foot	$500K
• Parking lot for 150 cars—20,000 square feet	50K
• Land—2 acres at $35,000* per acre	70K
Landscaping and access	
Total	$620K

*Values noted in Assumptions, Table 2-2.

In real circumstances, the facilities could not be justified solely by a single project, such as the support frustum manufacture. Additional work would be required and this would in turn reduce the apportioned costs to the manufacture of the support frustum. However, for this analysis, the entire costs are used to form a basis of comparison between various manufacturing technologies and to analyze impact of program factors.

5.1.2.4 Near-Term Pre-Manufacturing Operations

The pre-manufacturing operations, itemized in Table 5-11 are the same activities as with Element No. 2. The costs were recomputed for the support frustum structure manufacture with the results as indicated in Table 5-11. Learning curves, where applicable, can be applied to the recurring costs.

As with the propellant tank structure, a 40-percent recycle of activities was assumed to handle changes. This factor applies to the non-recurring costs—though use of the learning curves would have the effect of reducing this recycle. Based on experiences with Apollo/Saturn components, this 40-percent recycle factor seems conservative—in many cases, such as noted in Reference 8, costs may double because of change activities characteristic to aerospace equipment.

5.1.2.5 Summary

The complete cost tabulation for 2 per year and 20 per year production rate is shown in Tables 5-11 and 5-12. A summary for each calculation is shown on the respective tables.

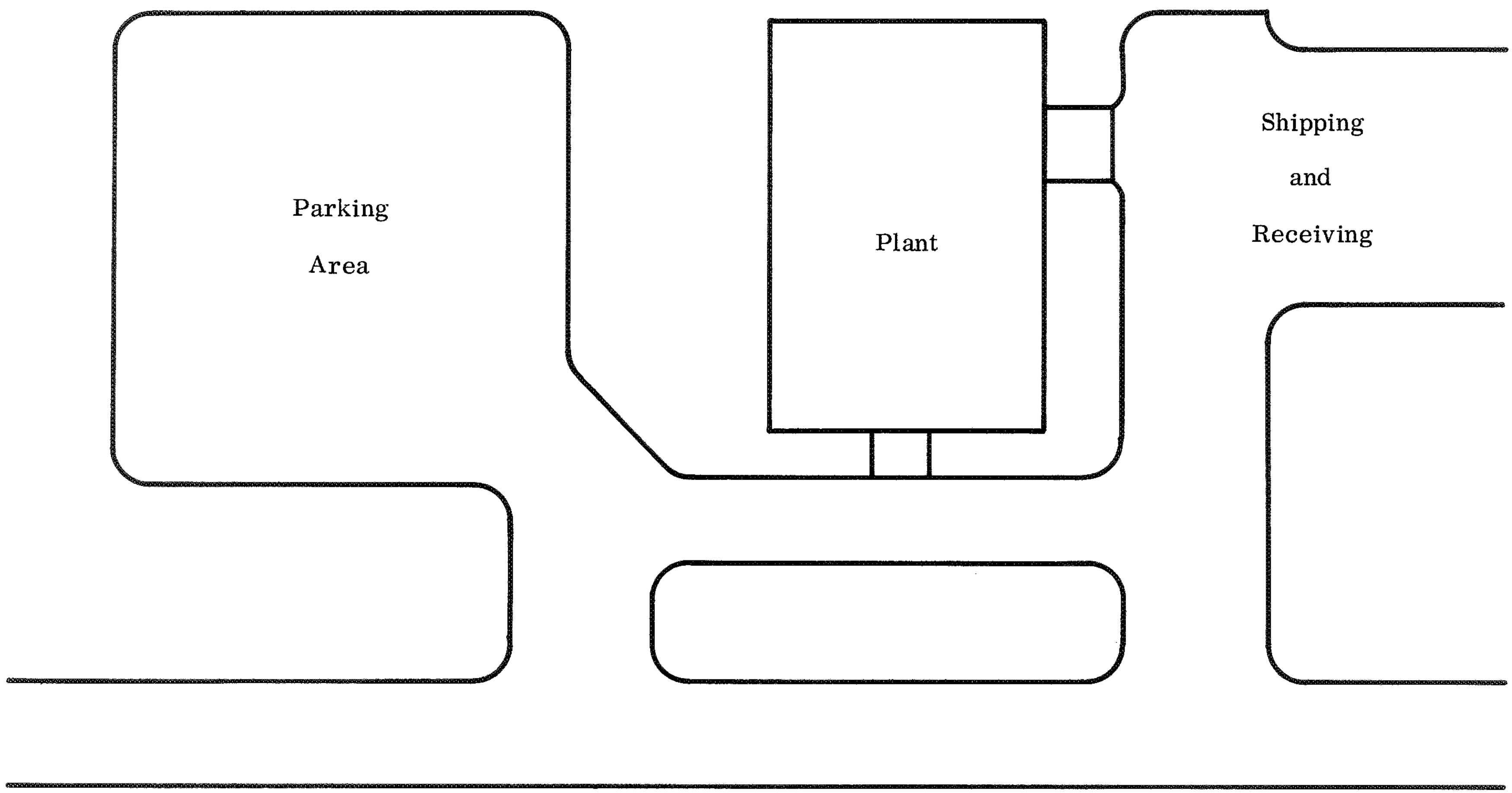


Figure 5-4. Representative Facilities to Produce Support Frustum Structures

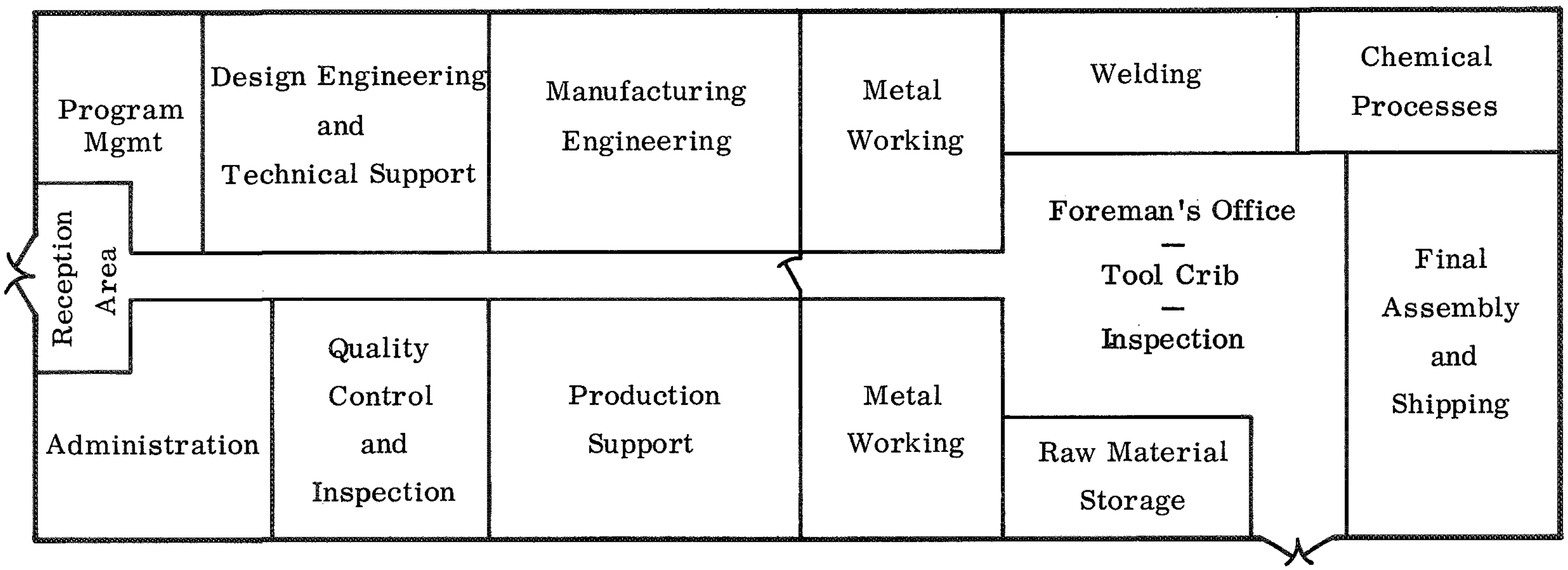


Figure 5-5. Office Area and Factory Space Allocation—Support Frustum (Element 1)

5.2 ANALYSIS OF STATE-OF-THE-ART MANUFACTURING LINE, LINE 1

Analysis of the state-of-the-art manufacturing lines for structural Elements 1 and 2 has resulted in the identification of problem areas and their solutions as shown in Table 5-13. Solutions to the identified problem areas are categorized as follows:

- Category I—Solutions immediately available.
- Category II—Solutions that require some technology development.
- Category III—Solutions that require major technology development.

When Category I solutions are incorporated into the state-of-the-art manufacturing line, it will become the improved line and when Category II and III solutions are incorporated into the improved line, it will become the advanced line.

Table 5-13

Representative Problem Areas (Areas for Potential Improvement)
Line 1 Problem Area
(Structural Element 2)

Problem 1

Facilities—The geographic separation of Plant 1 (Detail Fabrication) from Plant 2 (Assembly) is costly.

Solution (Category I)

Consolidate Facilities.

Five Year Program Savings

Item	2 Per Year (10 Tanks) Cost ($)	20 Per Year (100 Tanks) Cost ($)
Transportation		
Plant 1 to Plant 2		
Containers	+$24,100	+$ 72,300
Shipping	+$39,000	+$390,000
Facilities (Separated)		
Plant 1	$2,881,190	$ 6,925,317
Plant 2	6,502,850	15,907,850
Total Cost	$8,384,040	$22,833,167
Facilities (Consolidated)	-6,971,500	-16,679,882
Δ Cost (Saved)	+$1,412,540	+$ 6,153,285

Table 5-13 (Continued)

Representative Problem Areas (Areas for Potential Improvement)
Line 1 Problem Area
(Structural Element 2)

Five Year Program Savings

Item	2 Per Year (10 Tanks) Cost ($)	20 Per Year (100 Tanks) Cost ($)
Taxes (5 Years Saved)		
$\$1,412,540 \times \frac{*30}{1000} \times 5$ years	$ 211,881	
$\$6,153,285 \times \frac{30}{1000} \times 5$ years		$ 922,993
Savings—Total	1,687,521	7,538,578
Savings—Total/Tank	168,752	75,386

Problem 2

Welding—Costly and impacts quality.

Domes	610 feet
Cylinder	250 feet
Rings	
Common Bulk	340 feet
Cylinder	540 feet
Miscellaneous	60 feet
	1,800 feet of weld

Labor and Material Cost/Foot

Welding	$ 7.00
X-ray ($2/single pass)	4.00
	$11.00**

Solution (Category I)

Convert vertical mill for manually operated spinning of domes.

Spin domes (4)—Eliminate 610 feet of weld per tank, related equipment and inspections. (Impact on quality and cost to be determined.)

Solution (Category III)

Develop improved welding techniques for welding cylinder segments, Y-rings, cylinder to dome rings, and jamb and dollar covers.

Reduce number of cylinder segments from seven to four by utilizing wider rolling mill (would require a 220-inch mill). Saves 105 feet of welding. (Impact on quality and cost to be determined.)

*Assessment (County Area—Volusia County, Florida)
**Not including equipment and set-up labor

Table 5-13 (Continued)
Representative Problem Areas (Areas for Potential Improvement)
Line 1 Problem Area
(Structural Element 1 and 2)

Solution (Category III)

Eliminate all cylinder segment welds, roll form cylinder section in one single piece from an aluminum billet and chem mill structural pattern (waffles) or diffusion bond stiffeners to thin rolled cylinder. (Feasibility and impact on cost require further study)

Problem 3

Common bulkhead bonding costly and impacts quality. Currently bonding operation requires an estimated 2,000 man-hours of labor to fit and bond honeycomb in place.

Solution (Category III)

Utilize a diffusion bonding process applicable to compound curved surfaces. (Impact on cost and quality and feasibility require further study)

Problem 4

Program cost is impacted significantly by changes. Estimates of the overall impact of changes based upon past experience at the General Electric Company and other industrial survey interviews, the following breakdown of completed program cost is indicated.

Cost of Basic Program	35 percent
Cost of Engineering Required Changes	25 percent
Cost of Customer Required Changes	40 percent
	100 percent

Solution (Category III)

a. Develop a more precise implementation of phased planning to insure minimum changes.
b. Implement a more firm change control system.
c. Apply block system effectivity to change incorporation.

Problem 5—Study Element 1

Aerospace materials are expensive because of exacting specifications and the rigid quality control that must be applied and verified.

Solution (Category I)

Material, machining and quality assurance costs of machined rings manufactured from forgings can be reduced by the purchase of forgings from which multiple rings can be machined.

Table 5-13 (Continued)

Representative Problem Areas (Areas for Potential Improvement)
Line 1 Problem Area
(Structural Element 1 and 2)

Problem 6—Study Elements 1 and 2

Incomplete knowledge of manufacturing limitations and shop capabilities by design engineering causes more costly designs.

Solution (Category II)

Information systems with large memories and visual displays are becoming available. These systems will make it practical to keep the design engineer up-to-date on the various standard size and shapes of materials and shop processing and tooling capabilities.

Problem 7—Study Element 1

Reduce the many detail and costly operations in connection with riveting with a faster and simpler joining technique.

Solution (Category III)

Roll and spot-welding could be used to a greater extent in aerospace structures if process reliability could be improved. These processing improvements are within the range of reasonable expectations within the next decade.

Problem 8—Study Element 1

The many detail parts add to cost since they all require varying amounts of support time.

Solution (Category III)

Numerically-controlled machinery centers with simplified programming will make it possible to machine aerospace structures from single forgings.

Additional areas of improvements can be identified in almost every area where significant costs are currently incurred. These areas are touched on briefly in Section 6 of this report and are tabulated in matrices that show impact of variations of these factors on costs.

5.3 DESCRIPTION, IMPROVED MANUFACTURING LINE, LINE 2

5.3.1 PROPELLANT TANK STRUCTURE (ELEMENT 2)

5.3.1.1 General

The improved manufacturing line, Line 2, incorporates the solution to problem 1, the consolidation of facilities, and the Category I solution to problem 2, the elimination of 610 feet of welding per tank by spinning all domes (Table 5-13, paragraph 5.2).

5.3.1.2 Manufacturing Processes and Methods

The manufacturing processes of Line 1 concerned with the dome segment forming, trimming, and welding into complete domes have been replaced with a series of spinning operations. The new manufacturing processes as well as new material costs are shown in Table 5-14. The change in material cost is primarily the result of shear spinning the domes from a single plate rather than forming from nine separate segments where a large percentage of the material is scrapped.

As with Line 1, as each new manufacturing process was defined and placed into its respective sequence, an analysis was made of each of the manufacturing processes to determine its material cost as applicable and its man-hour requirements for manufacturing and quality control. The results of these analyses, along with defined and sequenced manufacturing processes, are also shown in Table 5-14.

Table 5-14

Manufacturing Processes for Propellant Tank Structure (Element 2)
Improved Manufacturing Line (Line 2)

MANUFACTURING PRØCESSES ======================	MAT'L CØST (K$)	Q.C. LABØR (M/HR)	MFG. LABØR (M/HR)	TØTAL CØST (K$)
1000 TANK ASSEMBLY				
1001 INSPECT FØRWARD DØME	0	20	10	0.45
1002 INSPECT LØX TANK	0	40	10	0.75
1003 MØVE DØME&LX TK TØ ASM TWR	0	0	20	0.3
1004 WELD CYL TØ LX TK(INT)&INSP	0.62	112	172	4.88
1005 WELD CYL TØ LX TK(EXT)&INSP	0.62	52	52	2.18
1006 WELD CYL TØ FWD DØME(INT)	0.62	112	142	4.43
1007 WELD CYL TØ FWD DØME(EXT)	0.62	102	102	3.68
1008 HYDRØSTATIC TEST	0	200	400	9
1009 DEGREASE	0	50	100	2.25
1010 WEIGHT & STØRE	0	20	125	2.175
1020 LØX TANK ASSEMBLY				
1021 MATE C BLK/A-DØM:SEAL & INSP	1.98	156	160	6.72
1022 X-RAY ALL WELDS, WEIGH	0.28	20	40	1.18
1023 MØVE TØ ASSEMBLY AREA	0	5	10	0.225
1030 AFT DØME ASSEMBLY				
1031 VERIFY MATERIAL FØR AFT DØME	2.6	0	0	2.6
1032 SCRIBE & SAW BLKS TØ REQ'D SHAPE	0	16	32	0.72
1033 SHEAR SPIN FØRM AND INSPECT	0	20	46	0.99
1034 CLEAN, ANNEAL, QUENCH, & INSPECT	0	24	32	0.84
1035 SPIN FØRM TØ SHAPE AND INSPECT	0	30	60	1.35
1036 CLEAN, ANNEAL, QUENCH, & INSP.	0	24	32	0.84
1037 FINAL FØRM SPIN & INSPECT	0	30	60	1.35
1038 CUT&TRM S-ØP'NG, DEBURR & INSP	0	8	26	0.51
1039 CLEAN, H-TREAT, AGE, INSP, & STØRE	0	30	54	1.26
1040 MASK, CHEM-MILL, DEBURR & INSP.	7.8	90	0	9.15
1041 CLEAN, ANØDIZE, & INSPECT	0	18	27	0.675
1042 WEIGH AND STØRE	0	5	9	0.21
1043 WELD JAMB & INSPECT	0.28	13	18	0.745
1044 WELD STUDS, FITTINGS, & INSPECT	0.22	19	23	0.85
1045 GRIND ALL WELDS, &DIE-PEN INSP.	0	60	200	3.9
1046 PERFØRM LEAK CHECK	0.1	10	30	0.7
1047 X-RAY ALL WELDS & WEIGH	0.3	95	4	1.785
1048 TRANSPØRT TØ LØX TANK ASSY AREA	0	5	10	0.225
1050 CØMMØN BULKHEAD ASSEM				
1051 ETCH CLEAN AFT DØME	0.2	15	30	0.875
1052 ETCH CLEAN FWD DØME	0.2	15	30	0.875
1053 FIT&BND HNYCMB & INSPECT	3.8	400	1600	33.8
1054 BUT WLD Y RNGS LK CHK&INSP	0.64	22	42	1.6
1055 MACHINE RING BUT WELDS	0	20	80	1.5
1056 XRAY WLD, ULT/INSP DØME, WGH & STR	4.24	30	10	4.84
1060 CØMMØN BLKHD FWD DØME				
1061 VERIFY CØM BULKHEAD FWD DØME	0.8	0	0	0.8
1062 SCRIBE & SAW BLK TØ REQ'D SHAPE	0	16	32	0.72
1063 SHEAR SPIN FØRM & INSPECT	0	20	46	0.99
1064 CLEAN, ANNEAL, QUENCH & INSPECT	0	24	32	0.84
1065 SPIN FØRM TØ SHAPE & INSPECT	0	30	60	1.35
1066 CLEAN, ANNEAL, QUENCH & INSPECT	0	24	32	0.84
1067 FINAL FØRM SPIN & INSPECT	0	30	60	1.35
1068 CUT&TRM S-ØP'NG TØ SIZ, DEBR&INSP	0	8	26	0.51
1069 CLEAN, H-TREAT, AGE INSP & STØRE	0	30	54	1.26

Table 5-14 (Continued)

Manufacturing Processes for Propellant Tank Structure (Element 2)
Improved Manufacturing Line (Line 2)

1070	MASK, CHEM-MILL, DEBURR & INSPECT	3.8	90	0	5.15
1071	CLEAN, ANØDIZE, & INSPECT	0	27	36	0.945
1072	WELD DØME TØ RING & INSPECT	0.64	26	34	1.54
1073	WELD CNTR $-CAP TØ DØME, INSP	0.28	13	20	0.775
1074	GRIND ALL WELDS & DIE-PEN INSP	0	60	200	3.9
1075	X-RAY ALL WELDS	0.23	0	0	0.23
1076	PERFØRM LEAK CHK, WEIGH & STØRE	0.1	15	40	0.925
1080	RING-FWD DØME-CØMMØN BULK				
1081	VRY MAT FØR 1FWD DØM Y RNG	0.35	0	0	0.35
1082	FØRM & INSPECT	0	14	26	0.6
1083	TRM, CLN, AGE & INSPECT	0	4	14	0.27
1084	ANØDIZE, WEIGH & STØRE	0	4	8	0.18
1085	WLD SEG, STRAIGTEN RNG&INSP	0	40	80	1.8
1086	MILL RNG FACE, INSP&STØRE	0	25	50	1.125
1090	CØMMØN BULKHEAD AFT DØME				
1091	VERIFY CØMMØN BULK AFT DØME MATL	0	0	0	0
1092	SCRIBE&SAW BLK TØ REQ'D SHAPE	0	16	32	0.72
1093	SHEAR SPIN FØRM & INSPECT	0	20	46	0.99
1094	CLEAN, ANØDIZE, QUENCH, & INSPECT	0	24	32	0.84
1095	SPIN FØRM TØ SHAPE & INSPECT	0	30	60	1.35
1096	CLEAN, ANNEAL, QUENCH, & INSPECT	0	24	32	0.84
1097	FINAL FØRM SPIN & INSPECT	0	30	60	1.35
1098	CUT&TRM $-ØP'NG , DEBURR& INSP	0	8	26	0.51
1099	CLEAN, H-TREAT, AGE, INSP & STØRE	0	30	54	1.26
1100	MASK, CHEM-MILL, DEBURR& INSP	3.2	90	0	4.55
1110	CLEAN, ANØDIZE, & INSPECT	0	27	36	0.945
1111	WELD DØME TØ RING & INSPECT	0.64	26	34	1.54
1112	WELD CNTR $-CAP TØ DØME, INSP	0.28	13	20	0.775
1113	GRIND ALL WELDS, DIE-PEN INSP	0	60	200	3.9
1114	X-RAY ALL WELDS	0.46	0	0	0.46
1115	PERFØRM LEAK CHK, WEIGH & STØRE	0.1	15	40	0.925
2010	RING-AFT DØME CØMMØN BULK				
2011	VRFY MAT FØR 1AFT DØME Y RNG	0.35	0	0	0.35
2012	FØRM & INSPECT	0	14	26	0.6
2013	TRIM, CLEAN, AGE & INSPECT	0	4	14	0.27
2014	ANØDIZE, WEIGH & STØRE	0	4	8	0.18
2015	WLD SEG, STRAIGHTEN RNG&INSP	0	40	80	1.8
2016	MILL RNG FACE, INSPECT& STØRE	0	25	50	1.125
2020	TANK CYLINDER				
2021	VRFY MAT'L FØR 7 TANK SEG'S	31	0	0	31
2022	MILL EDGES	6.5	28	56	7.76
2023	MILL WAFFLE	32.5	28	56	33.76
2024	ULTRASØNIC INSPECT	13.85	0	0	13.85
2025	MØVE 7 SEGS TØ ASSY AREA	0	7	14	0.315
2027	DRILL SPREADER BAR HØLES	0	14	28	0.63
2029	HEAT TREAT (ANNEAL)	0	0	14	0.21
2030	FØRM 7 SKINS, CLN, AGE, INSP	0	98	203	4.515
2031	ANDZ, TRM, WGH, INSTL SPR BARS	0	31	45	1.14
2041	WELD 7 SEGMENTS & INSP	2.2	106	212	6.97
2043	TRIM CYL & WELD RINGS	1.27	34	66	2.77
2044	XRAY ALL WLDS, WEIGH &STØRE	2.6	20	80	4.1

Table 5-14 (Continued)

Manufacturing Processes for Propellant Tank Structure (Element 2)
Improved Manufacturing Line (Line 2)

2050	RING TANK CYL				
2051	VRFY MAT FØR 2 RNGS(CYL)	0.7	0	0	0.7
2052	FØRM 8 SEG & INSPECT	0	28	52	1.2
2053	TRIM, AGE, INSPECT	0	8	28	0.54
2054	ANØDIZE WEIGH & STØRE	0	8	16	0.36
2055	WLD SEG, STRTN 2 RNGS&INSP	0	80	160	3.6
2056	MILL RNG FACE, INSP, WEIGH	0	45	90	2.025
2057	MØVE 2 RINGS TØ ASSEM. AREA	0	5	10	0.225
2060	FØREWARD DØME				
2061	VERIFY MAT'L FØR FWD DØME	1.3	0	0	1.3
2062	SCRIBE&SAW BLK TØ REQ'D SHAPE	0	16	32	0.72
2063	SHEAR SPIN FØRM & INSPECT	0	20	46	0.99
2064	CLEAN, ANNEAL, QUENCH, & INSPECT	0	24	32	0.84
2065	SPIN FØRM TØ SHAPE & INSPECT	0	30	60	1.35
2066	CLEAN, ANNEAL, QUENCH, & INSPECT	0	24	32	0.84
2067	FINAL FØRM SPIN & INSPECT	0	30	60	1.35
2068	CUT&TRM $-ØP'NG, DEBUR&INSP.	0	8	26	0.51
2069	CLEAN, H-TREAT, AGE, INSP & STØRE	0	30	54	1.26
2070	MASK, CHEM-MILL, DEBURR, & INSP.	7.8	90	0	9.15
2071	CLEAN, ANØDIZE, & INSP.	0	18	27	0.675
2072	WEIGH & STØRE	0	5	9	0.21
2073	WELD JAMB & INSPECT	0.28	13	18	0.745
2074	WELD STUDS, FITTINGS, & INSP.	0.22	19	23	0.85
2075	GRIND ALL WELDS, DIE-PEN INSP.	0	60	200	3.9
2076	PERFØRM LEAK CHECK	0.1	10	30	0.7
2077	X-RAY ALL WELDS & WEIGH	0.3	95	4	1.785
2078	LØAD, MØVE DØME TØ ASSY AREA	0	6	12	0.27
		-------	------	------	----------
		136.97	3926	7293	305.255
	LABØR CØST (K$)		(58.89)	(109.395)	

5.3.1.3 Tooling

The Line 1 tooling list, Table 5-1, was modified to delete the dome segment stretch forming equipment and incorporate dome shear spinning equipment. The tooling requirements for the low production rate spinning utilized a modified vertical boring mill for spinning and the higher production rate tooling requirements incorporate a new spinning mill. The cost of this spinning equipment was supplied by the Air Force Materials Laboratory.

The modified tooling list incorporates the above change for Line 2 for both the 2 per year and 20 per year production rates and is shown in Table 5-15.

5.3.1.4 Facilities (Buildings)

The manufacturing and assembly plants for the improved manufacturing line for each of the two production rates have been combined such that each line is in its own building. In determining the cost of the facilities to house the improved manufacturing lines, one having a 2 per year production rate and the other 20 per year, it was assumed that the manufacturing area would have 30-foot ceilings and the assembly area would have 100-foot ceilings, the same as for Line 1.

The floor areas for each of the buildings were established based upon providing facilities for the number of personnel required and combining the floor area requirements for each Line 1 and adjusting for other elements shown in Table 5-16.

In arriving at the total cost of each of the consolidated plants, as for the Line 1 manufacturing plant, land cost and improvements for land designated commercial in the vicinity of Daytona Beach, Florida were set at $12,000 per acre plus $18,500 per acre for improvement. Other cost items, including $18 per square foot of low-bay (30-foot ceiling) area and $60 per square foot of high-bay (100-foot ceiling) area, were estimated based upon information contained in Reference 2 and information provided by the General Electric Company facility section. The total cost of each plant is summarized in Table 5-17.

Table 5-15

PROPELLANT TANK STRUCTURE (Element 2)

TOOL REQUIREMENTS/APPLICATION/UNIT COST
LINE # 2

TOOL IDENTIFICATION			APPLICATION											*PER TOOL		
			DOME		COMMON BULKHEAD					TANK CYLINDER				PROD		
					DOME		RING									
NO.	NAME	UNIT COST $/K	FWD	AFT	FWD	AFT	FWD	AFT	ASSY	CYL	RING	ASSY	TANK ASSEMBLY	2/YEAR	20/YEAR	ALLOWABLE * SQ. FOOTAGE
100	Power Saw	8.0	X	X	X	X								1	3	
101	Work Platform	2.0	X	X	X	X								1	3	
102	Scribe Arm	1.0	X	X	X	X								1	3	
110	Vertical Boring Mill	350.0	X	X	X	X	X	X			X			1	-	
111	Rollers) Modified additions required	25.0	X	X	X	X								1	-	
112	Stake) to Boring Mill	25.0	X	X	X	X								1	-	
113	Heat Manifold)	35.0	X	X	X	X								1	-	
114	Station Cutter)	15.0	X	X	X	X								1	-	
120	Lathe Fixture No. 1	12.0					X							1	1	
121	Lathe Fixture No. 2	12.0						X						1	1	
122	Lathe Fixture No. 3	12.0									X			1	1	
	Spinning Mill—Power Shear—NC	3250.0	X	X	X	X	X	X			X			-	1	
140	Heat Treat Oven (25'x25'x40')	350.0	X	X	X	X	X	X		X	X			1	2	
141	Quench Tank (25'x25'x40')	100.0	X	X	X	X	X	X		X	X			1	1	
150	Dome Rotating Tool	125.0			X	X								1	1	
151	Etch Cleaning Tank (25'x25'x12')	50.0			X	X								1	1	
152	Etch Cleaning Tank (25'x25'x40')	100.0	X	X	X	X	X	X		X	X			1	1	
160	Jamb Ring Welder Stand	30.0	X	X	X	X								1	2	
161	Jamb Clamps	2.0	X	X										1	2	
162	Jamb Ring/Dollar Opening Trimmer	5.0	X	X	X	X								1	2	
163	Jamb Ring/Dollar Welder	7.0	X	X	X	X								1	2	
164	X-ray Unit	18.0	X	X	X	X								1	2	

NC—Numerically Controlled

Table 5-15 (Continued)

PROPELLANT TANK STRUCTURE (Element 2)

TOOL REQUIREMENTS/APPLICATION/UNIT COST LINE #2

TOOL IDENTIFICATION			APPLICATION											*PER TOOL		
NO.	NAME	UNIT COST $/K	DOME		COMMON BULKHEAD					TANK CYLINDER			TANK ASSEMBLY	PROD		ALLOWABLE * SQ. FOOTAGE
					DOME		RING									
			FWD	AFT	FWD	AFT	FWD	AFT	ASSY	CYL	RING	ASSY		2/YEAR	20/YEAR	
170	Spray Booth	20.0	X	X	X	X								1	1	
171	Neoprene Maskat Spray	4.0	X	X	X	X								1	1	
172	Maskant Cut Stencil No. 1	1.0	X											4	8	
173	Maskant Cut Stencil No. 2	1.0		X										4	8	
174	Maskant Cut Stencil No. 3	1.0			X									4	8	
175	Maskant Cut Stencil No. 4	1.0				X								4	8	
180	Chem Mill (25'x25'x12')	75.0	X	X	X	X								1	2	
190	Anodize (25'x25'x40')	75.0	X	X	X	X	X	X		X	X			2	4	
200	Load Cell No. 1	2.0	X	X	X	X	X	X		X	X			1	1	
201	Hoist Spreader Bar No. 1	.8	X	X	X	X								1	1	
202	Hoist Spreader Bar No. 2	.8					X	X			X			1	1	
203	Hoist Spreader Bar No. 3	.8								X				1	1	
204	Pick-up Positioner	7.0	X	X										1	2	
205	Stud Welder Head	10.0	X	X										1	2	
210	Weld Grinder (Portable)	1.0	X	X	X	X	X	X		X	X			3	6	
220	Ammonia Gas Pressure Test Rig	10.0	X	X	X	X			X					1		
230	X-ray Holding Fixture	15.0	X	X	X	X			X					1	4	
231	X-ray Unit	18.0	X	X	X	X			X					1	4	
240	Transport Fixture	4.0	X	X					X					2	6	
250	Dome to Ring Weld Fixture	12.0			X	X								1	1	
251	Welding Head	18.0			X	X								1	1	
252	X-ray Unit	18.0			X	X								1	1	

Table 5-15 (Continued)

PROPELLANT TANK STRUCTURE (Element 2)

TOOL REQUIREMENTS/APPLICATION/UNIT COST LINE #2																
TOOL IDENTIFICATION			APPLICATION											*PER TOOL		
			DOME		COMMON BULKHEAD					TANK CYLINDER				PROD		
					DOME		RING									
NO.	NAME	UNIT COST $/K	FWD	AFT	FWD	AFT	FWD	AFT	ASSY	CYL	RING	ASSY	TANK ASSEMBLY	2/YEAR	20/YEAR	ALLOWABLE * SQ. FOOTAGE
260	Stretch Press	20.0					X	X			X			1	1	
261	Ring Die No. 1	2.0					X							1	1	
262	Ring Die No. 2	2.0						X						1	1	
263	Ring Die No. 3	2.0									X			1	1	
270	Ring Extrusion Cutter	.5					X	X			X			1	1	
271	Ring Weld Fixture	20.0					X	X			X			1	1	
272	Ring Weld Fixture Set 1	1.0					X	X						1	1	
273	Ring Weld Fixture Set 2	1.0									X			1	1	
274	Welding Head	10.0					X	X			X			1	1	
280	Bonding Gantry	40.0							X					1	4	
281	Heat/Pressure Dome	80.0							X					1	4	
282	Vacuum Bag	8.0							X					1	4	
283	Bleeder Cloth	2.0							X					1	4	
284	Vacuum Pump	2.0							X					1	4	
285	Sonic Measuring Device and Automatic Readout	25.0							X	X				1	4	
290	Common Bulkhead Ring Butt Weld Fixture	8.0							X					1	2	
291	Welding Head	18.0							X					1	2	
300	Common Bulkhead Lathe Fixture	12.0							X					1	1	
301	Ring Cutting Tool	1.0							X					1	1	
310	Spreader Bars (Hoist)	1.0							X					1	2	
311	Load Cell	2.0							X					1	2	
320	LOX Tank Weld Fixture	35.0							X					1	3	
321	Drill	1.0							X					1	3	
322	Drill Jig	2.0							X					1	3	

Table 5-15 (Continued)

PROPELLANT TANK STRUCTURE (Element 2)

TOOL REQUIREMENTS/APPLICATION/UNIT COST
LINE #2

TOOL IDENTIFICATION			APPLICATION													*PER TOOL
			DOME		COMMON BULKHEAD					TANK CYLINDER				PROD		
					DOME		RING									
NO.	NAME	UNIT COST $/K	FWD	AFT	FWD	AFT	FWD	AFT	ASSY	CYL	RING	ASSY	TANK ASSEMBLY	2/YEAR	20/YEAR	ALLOWABLE SQ. FOOTAGE *
323	Welder	18.0							X					1	3	
330	Skin Mill (10' x 40')	500.0								X				1	1	
340	Drill Template	.5								X				2	4	
341	Power Drill	1.0								X				2	4	
350	Brake—40'	150.0								X				1	1	
360	Segment Trim Fixture	35.0								X				1	2	
361	Power Cutter	5.0								X				1	2	
370	Spreader Bars	.2										X		14	28	
371	Longitudinal Weld Fixture	45.0										X		1	2	
372	Welder Head	18.0										X		1	2	
380	End Trim/Ring Weld Dolly	75.0										X		1	2	
381	Weld Fixture	5.0										X		1	2	
382	Welder Head	18.0										X		1	2	
410	X-ray Unit	18.0										X		1	1	
420	Hoist Spreader Bar	1.5										X		2	4	
421	Load Cell	2.0										X		1	2	
430	Tank Assembly Tower	200.0											X	1	6	
431	Heat Blanket	12.0											X	1	6	
432	Welder Head	18.0											X	1	6	
433	X-ray Unit	18.0											X	1	6	
434	Hoisting Yoke and Crane	50.0											X	1	6	

Table 5-15 (Continued)

PROPELLANT TANK STRUCTURE (Element 2)

TOOL REQUIREMENTS/APPLICATION/UNIT COST
LINE # 2

TOOL IDENTIFICATION			APPLICATION													*PER TOOL
			DOME		COMMON BULKHEAD					TANK CYLINDER				PROD		
					DOME		RING									
NO.	NAME	UNIT COST $/K	FWD	AFT	FWD	AFT	FWD	AFT	ASSY	CYL	RING	ASSY	TANK ASSEMBLY	2/YEAR	20/YEAR	ALLOWABLE * SQ. FOOTAGE
440	Hydrostatic Test Equipment	100.0											X	1	6	
441	Degreaser	80.0											X	1	6	
450	Tank Dolly	40.0											X	1	6	
451	Hoist Yoke	10.0											X	1	6	
452	Load Cell	2.0											X	1	6	

Table 5-16

Manufacturing and Assembly Plant Floor Areas

PRODUCTION RATE ⟶	2 Per Year	20 Per Year
NO. OF PERSONNEL* ⟶	450	1,350
ITEM	Floor Area Square Feet	Floor Area Square Feet
Machine and Tool Area	75,660	207,488
Aisle Ways and Entry Area	34,250	105,250
Storage Area Materials	57,000	125,000
Eating Area	5,000	7,500
Loading Dock Extension	7,000	14,500
Office Space	1,500	1,800
Dispensary	1,120	1,120
Toilet Facilities	1,000	1,000
Fork Lift Park Area	150	210
Transporter Storage Area	1,900	3,800
Clean Room and Compressor Area	29,360	46,666
Vending Machine Area	60	90
Total	214,000	514,424
30-Foot Ceiling (Est) Area	164,000	374,424
100-Foot Ceiling (Est) Area	50,000	140,000

*For Sizing Only

5.3.1.5 Transportation

With the consolidation of the manufacturing and assembly plants in accordance with the solutions to problem 1, Table 5-13, shipping containers and transportation cost between plants is eliminated.

5.3.1.6 Near-Term Pre-Manufacturing Operations

It is assumed that this cost, both recurring and non-recurring, will be the same as for Line 1. Refer to Table 5-8, paragraph 5.1.1.6.

5.3.1.7 Improved Manufacturing Line Summary

The cost elements for production rates of 2 and 20 tanks per year discussed in paragraph 5.3.1 are summarized utilizing MANCAN program, and are shown in Tables 5-18 and 5-19.

Table 5-17

Land Acquisition and Building Construction Requirements/Cost
Propellant Tank Structure, Element 2
Improved Manufacturing Line (Line 2)
Manufacturing and Assembly Plant (Consolidated)

2 Per Year		20 Per Year	
Item	Cost ($)	Item	Cost ($)
Land—8.0 acres (Including Required Improvements)	244,000	Land—13.5 acres (Including Required Improvements)	411,750
Sewage Plant	300,000	Sewage Plant	345,000
Outside Storage Sheds	25,500	Outside Storage Sheds	60,000
Dock Requirements	13,500	Dock Requirements	18,000
Main Plant x 30-Foot Ceiling 164,000 sq. ft. 100-Foot Ceiling 50,000 sq. ft.	5,952,000	Main Plant x 30-Foot Ceiling 374,424 sq. ft. 100-Foot Ceiling 140,000 sq. ft.	15,139,632
Dispensary	32,000	Dispensary	36,000
Bridge Cranes (1 10-Ton and 1 20-Ton)	90,000	Bridge Cranes (2 10-Ton and 2 20-Ton)	180,000
Wall Partitions (Portable), Doors, Storage Bins and Fixtures	110,000	Wall Partitions (Portable), Doors, Storage Bins and Fixtures	175,000
Toilet Facilities	15,000	Toilet Facilities	17,500
Office Furniture	6,500	Office Furniture	7,000
Air Lines, Compressors. Filters and Fire Protection System *	150,000	Air Lines, Compressors, Filters and Fire Protection System**	250,000
Fork Lift Trucks (4) and Tugs (2)	33,000	Fork Lift Trucks (6) and Tugs (2)	40,000
Total	6,971,500	Total	16,679,882

* Includes One Clean Room

** Includes Two Clean Rooms

x Building Temperature Controlled, Price Includes Heating, Air Conditioning and Insulation—$18/sq.ft. 30-foot ceiling
$60/sq. ft. 100-foot ceiling

Table 5-18

Manufacturing Cost Analysis

MANUFACTURING CØST ANALYSIS
****
09/22/70

LINE: IMPRØVED MANUFACTURING LINE (LINE 2)

STRUCTURE: PRØPELLANT TANK STRUCTURE (ELEMENT 2)

PRØDUCTIØN RATE: 2 PER YEAR

VARIATIØN FRØM THE NØMINAL: NØNE

TØTAL PRØGRAM LENGTH: 5 YEARS

LABØR RATES-($/HR): PRE-MFG.- 15. ; Q.C.- 15. ; MFG.- 15.

TØØLING	UNIT CØST (K$)	NØ. UNITS	TØTAL CØST (K$)
100 PØWER SAW	8	1	8
101 WØRK PLATFØRM	2	1	2
102 SCRIBE ARM	1	1	1
110 VERTICAL BØRING MILL	350	1	350
111 RØLLERS	25	1	25
112 STAKE	25	1	25
113 HEAT MANIFØLD	35	1	35
114 STATIØN CUTTER	15	1	15
120 LATHE FIXTURE # 1	12	1	12
121 LATHE FIXTURE # 2	12	1	12
122 LATHE FIXTURE # 3	12	1	12
140 HEAT TREAT ØVEN (25'X25'X40')	350	1	350
141 QUENCH TANK (25'X25'X40')	100	1	100
150 DØME RØTATING TØØL	125	1	125
151 ETCH CLEANING TANK (25'X25'X12')	50	1	50
152 ETCH CLEANING TANK (25'X25'X40')	100	1	100
160 JAMB RING WELDER STAND	30	1	30
161 JAMB CLAMPS	2	1	2
162 JAMB RING/DØLLAR ØPENING TRIMMER	5	1	5
163 JAMB RING/DØLLAR WELDER	7	1	7
164 X-RAY UNIT	18	1	18
170 SPRAY BØØTH	20	1	20
171 NEØPRENE MASKANT SPRAY	4	1	4
172 MASKANT CUT STENCIL # 1	1	4	4
173 MASKANT CUT STENCIL # 2	1	4	4
174 MASKANT CUT STENCIL # 3	1	4	4
175 MASKANT CUT STENCIL # 4	1	4	4
180 CHEM MILL (25'X25'X12')	75	1	75
190 ANØDIZE (25'X25'X40')	75	2	150
200 LØAD CELL # 1	2	1	2
201 HØIST SPREADER BAR #1	0.8	1	0.8
202 HØIST SPREADER BAR #2	0.8	1	0.8
203 HØIST SPREADER BAR #3	0.8	1	0.8
204 PICKUP PØSITIØNER	7	1	7
205 STUD WELDER HEAD	10	1	10
210 WELD GRINDER(PØRTABLE)	1	3	3
220 AMMØNIA GAS PRESSURE TEST RIG	10	1	10
230 X-RAY HØLDING FIXTURE	15	1	15
231 X-RAY UNIT	18	1	18
240 TRANSPØRT FIXTURE	4	2	8
250 DØME TØ RING WELD FIXTURE	12	1	12
251 WELDING HEAD	18	1	18
252 X-RAY UNIT	18	1	18
260 STRETCH PRESS	20	1	20
261 RING DIE #1	2	1	2
262 RING DIE #2	2	1	2
263 RING DIE #3	2	1	2
270 RING EXTRUSIØN CUTTER	0.5	1	0.5
271 RING WELD FIXTURE	20	1	20
272 RING WELD FIXTURE SET 1	1	1	1
273 RIND WELD FIXTURE SET 2	1	1	1
274 WELDING HEAD	10	1	10
280 BØNDING GANTRY	40	1	40
281 HEAT/PRESSURE DØME	80	1	80
282 VACUUM BAG	8	1	8
283 BLEEDER CLØTH	2	1	2
284 VACUUM PUMP	2	1	2
285 SØNIC MEASURING DEVICE& AUTØ RDØUT	25	1	25
290 CØMMØN BULKH RING BUTT WLD FIXT	8	1	8
291 WELDING HEAD	18	1	18
300 CØM BULKH LATHE FIXTURE	12	1	12
301 RING CUTTING TØØL	1	1	1
310 SPREADER BARS(HØIST)	1	1	1
311 LØAD CELL	2	1	2
320 LØX TANK WELD FIXTURE	35	1	35
321 DRILL	1	1	1
322 DRILL JIG	2	1	2
323 WELDER	18	1	18
330 SKIN MILL(10'X40')	500	1	500
340 DRILL TEMPLATE	0.5	2	1
341 PØWER DRILL	1	2	2
350 BRAKE-40'	150	1	150
360 SEGMENT TRIM FIXTURE	35	1	35
361 PØWER CUTTER	5	1	5
370 SPREADER BARS	0.2	14	2.8
371 LØNGITUDINAL WELD FIXTURE	45	1	45
372 WELDER HEAD	18	1	18
380 END TRIM/RING WELD DØLLY	75	1	75
381 WELD FIXTURE	5	1	5
382 WELDER HEAD	18	1	18
390 X-RAY UNIT	18	1	18
400 HØIST SPREADER BAR	1.5	2	3
401 LØAD CELL	2	1	2
430 TANK ASSEM TØWER	200	1	200
431 HEAT BLANKET	12	1	12
432 WELDER HEAD	18	1	18
433 X-RAY UNIT	18	1	18
434 HØISTING YØKE & CRANE	50	1	50
440 HYDRØSTATIC TEST EQUIP	100	1	100
441 DEGREASER	80	1	80
450 TANK DØLLY	40	1	40
451 HØIST YØKE	10	1	10
452 LØAD CELL	2	1	2
TØTAL TØØLING CØST (K$)			3395.7

FACILITIES	TØTAL CØST (K$)
500 CØNSØLIDATED MANUFACTURING & ASSEMBLY PLANT	6972

NEAR-TERM PRE-MANUFACTURING ØPERATIØNS

NØN-RECURRING CØSTS

ITEM	M/HRS	TØTAL CØST (K$)
800 REVIEW PRØGRAM DIRECTIVES	700.	10.5
810 MFG. PRELIMINARY SCHEDULES	700.	10.5
820 PRØDUCIBILITY STUDIES	9380.	140.7
830 IDENTIFY/ØRDER LØNG LEAD ITEMS	1890.	28.35
840 ACCUMULATE/REVIEW ENGR & QC DØCUMENT.	1890.	28.35
850 DEVELØP SUB-ASSEMBLY & PARTS SCHEDULE	9380.	140.7
860 MFG. PLANNING ØPERATIØNS	14000.	210
870 DESIGN/PRØCURE TØØLING	22400.	336
880 VENDØR EVALUATIØN & SELECTIØN	4200.	63
NØN-RECURRING TØTALS	64540.	968.1
RECURRING CØSTS		
900 EXPEDITE IN-HØUSE/PURCHASE PARTS	8000.	120
910 REVIEW PRØGRESS WITH PRØGRAM ØFFICE	2000.	30
RECURRING TØTALS	10000	150
TØTAL RECURRING AND NØN-RECURRING PRE-MFG. CØSTS=		1118.1

MANUFACTURING PRØCESSES	MAT'L CØST (K$)	Q.C. LABØR (M/HR)	MFG. LABØR (M/HR)	TØTAL CØST (K$)
1000 TANK ASSEMBLY				
1001 INSPECT FWD DØME	0	200	100	4.5
1002 INSPECT LØX TANK	0	400	100	7.5
1003 MØVE F/D+L/T TØ ASSY TØWER	0	0	200	3
1004 WELD CYL TØ L/T(INTER)+INSP	6.2	1120	1720	48.8
1005 WELD CYL TØ L/T(EXTER)+INSP	6.2	520	520	21.8
1006 WELD CYL TØ F/D(INTER)+INSP	6.2	1120	1420	44.3
1007 WELD CYL TØ F/D(EXTER)+INSP	6.2	1020	1020	36.8
1008 HYDRØSTATIC TEST	0	2000	4000	90
1009 DEGREASE	0	500	1000	22.5
1010 WEIGH+STØRE	0	200	1250	21.75
1020 LØX TANK ASSEMBLY				
1021 MATE C/B+A/D:SEAL WELD+INSP	19.8	1560	1600	67.2
1022 X-RAY ALL WELDS+WEIGH	2.8	200	400	11.8
1023 MØVE TØ A/A	0	50	100	2.25
1030 AFT DØME ASSY				
1031 VERIFY MTL FØR A/D	26	0	0	26
1032 SCRIBE+SAW BLK TØ REQ SHAPE	0	160	320	7.2
1033 SHEAR SPIN FØRM+INSP	0	200	460	9.9
1034 CLEAN+ANNEAL+QUENCH+INSP	0	240	320	8.4
1035 SPIN FØRM TØ SHAPE+INSP	0	300	600	13.5
1036 CLEAN+ANNEAL+QUENCH+INSP	0	240	320	8.4
1037 FINAL FØRMSPIN+STA TRIM+INSP	0	300	600	13.5
1038 CUT+TRIM C/C ØPNG+DEBURR+INSP	0	80	260	5.1
1039 CLN+HEAT TREAT+AGE+INSP+STØRE	0	300	540	12.6
1040 MASK+CHEM MILL+DEBURR+INSP	78	900	0	91.5
1041 CLEAN+ANØDIZE+INSP	0	180	270	6.75
1042 WEIGH+STØRE	0	50	90	2.1
1043 WELD JAMB+INSP	2.8	130	180	7.45
1044 WELD STUDS+FITTINGS+INSP	2.2	190	230	8.5
1045 GRIND ALL WELDS+DYE-PEN INSP	0	600	2000	39
1046 PERFØRM LEAK CHECK	1	100	300	7
1047 X-RAY ALL DØME WELDS+WEIGH	3.	950	40	17.85
1048 TRANSPØRT TØ L/T A/A	0	50	100	2.25
1050 CØMMØN BULKHEAD ASSY				
1051 ETCH CLEAN AFT DØME	2	150	300	8.75
1052 ETCH CLEAN FWD DØME	2	150	300	8.75
1053 FIT+BØND HØNEYCØMB+INSP	38	4000	16000	338
1054 BUTT WELD Y RINGS+LK CK+INSP	6.4	220	420	16
1055 MACHINE RING BUTT WELDS	0	200	800	15
1056 X-RAY WELD+U/I DØME+WGH+STØRE	42.4	300	100	48.4
1060 CØMMØN BULKHEAD F/D				
1061 VERIFY MTL FØR C/B F/D	8	0	0	8
1062 SCRIBE+SAW BLK TØ REQ SHAPE	0	160	320	7.2
1063 SHEAR SPIN FØRM+INSP	0	200	460	9.9
1064 CLEAN+ANNEAL+QUENCH+INSP	0	240	320	8.4
1065 SPIN FØRM TØ SHAPE+INSP	0	300	600	13.5
1066 CLEAN+ANNEAL+QUENCH+INSP	0	240	320	8.4
1067 FINAL FØRM SPIN+STA TRIM+INSP	0	300	600	13.5
1068 CUT+TRIM C/C ØPNG+DEBURR+INSP	0	80	260	5.1
1069 CLN+HEAT TREAT+AGE+INSP+STØRE	0	300	540	12.6
1070 MASK+CHEM MILL+DEBURR+INSP	38	900	0	51.5
1071 CLEAN+ANØDIZE+INSPECT	0	270	360	9.45
1072 WELD DØME TØ RING+INSP	6.4	260	340	15.4
1073 WELD CENTER CAP TØ DØME+INSP	2.8	130	200	7.75
1074 GRIND ALL WELDS+DYE-PEN INSP	0	600	2000	39
1075 X-RAY ALL WELDS	2.3	0	0	2.3
1076 PERFØRM LEAK CHECK+WGH+STØRE	1	150	400	9.25
1080 RING:F/D:CØMMØN BULKHEAD				
1081 VERIFY MTL FØR 1 F/D Y RING	3.5	0	0	3.5
1082 FØRM+INSP	0	140	260	6
1083 TRIM+CLEAN+AGE+INSP	0	40	140	2.7
1084 ANØDIZE+WEIGH+STØRE	0	40	80	1.8
1085 WELD SEG+STRAIGHTEN RING+INSP	0	400	800	18
1086 MILL RING FACE+INSP+STØRE	0	250	500	11.25
1090 CØMMØN BULKHEAD AFT DØME				
1091 VERIFY MTL FØR C/B AFT DØME	0	0	0	0
1092 SCRIBE+SAW BLK TØ REQ SHAPE	0	160	320	7.2
1093 SHEAR SPIN FØRM+INSP	0	200	460	9.9
1094 CLEAN+ANNEAL+QUENCH+INSP	0	240	320	8.4
1095 SPIN FØRM TØ SHAPE+INSP	0	300	600	13.5
1096 CHEAN+ANNEAL+QUENCH+INSP	0	240	320	8.4
1097 FINAL FØRM SPIN+STA TRIM+INSP	0	300	600	13.5
1098 CUT+TRIM C/C ØPNG+DEBURR+INSP	0	80	260	5.1
1099 CLN+HEAT TREAT+AGE+INSP+STØRE	0	300	540	12.6
1100 MASK+CHEM MILL+DEBURR+INSP	32	900	0	45.5
1110 CLEAN+ANØDIZE+INSP	0	270	360	9.45
1111 WELD DØME TØ RING+INSP	6.4	260	340	15.4
1112 WELD CENTER CAP TØ DØME+INSP	2.8	130	200	7.75
1113 GRIND ALL WELDS+DYE-PEN INSP	0	600	2000	39
1114 X-RAY ALL WELDS	4.6	0	0	4.6
1115 PERFØRM LEAK CHECK+WGH+STØRE	1	150	400	9.25
2010 RING:A/D:CØMMØN BULKHEAD				
2011 VERIFY MTL FØR 1 A/D Y RING.	3.5	0	0	3.5
2012 FØRM+INSP	0	140	260	6
2013 TRIM+CLEAN+AGE+INSP	0	40	140	2.7
2014 ANØDIZE+WEIGH+STØRE	0	40	80	1.8
2015 WELD SEG+STRAIGHTEN RING+INSP	0	400	800	18
2016 MILL RING FACE+INSP+STØRE	0	250	500	11.25
2020 TANK CYLINDER				
2021 VERIFY MTL FØR 7 TANK SEG(S)	310	0	0	310
2022 MILL EDGES	65	280	560	77.6
2023 MILL WAFFLE PATTERN	325	280	560	337.6
2024 ULTRASØNIC INSP	138.5	0	0	138.5
2025 MØVE SEG(S) TØ A/A	0	70	140	3.15
2027 DRILL SPREADER BAR HØLES	0	140	280	6.3
2029 HEAT TREAT(ANNEAL)	0	0	140	2.1
2030 FØRM 7 SKINS+CLN+AGE+INSP	0	980	2030	45.15
2031 ANØDIZE+TRIM+WGH+INSTL S/B(S)	0	310	450	11.4
2041 WELD SEG(S)+INSP	22	1060	2120	69.7
2043 TRIM CYL+WELD RINGS	12.7	340	660	27.7
2044 X-RAY ALL WELDS+WEIGH+STØRE	26	200	800	41
2050 RING TANK CYL				
2051 VERIFY MTL FØR 2 RINGS(CYL)	7.	0	0	7
2052 FØRM 8 SEG(S)+INSP	0	280	520	12
2053 TRIM+AGE+INSP	0	80	280	5.4
2054 ANØDIZE+WEIGH+STØRE	0	80	160	3.6
2055 WELD SEG+STRTN RINGS+INSP	0	800	1600	36
2056 MILL RING FACE+INSP+WEIGH	0	450	900	20.25
2057 MØVE RINGS TØ A/A	0	50	100	2.25
2060 FWD DØME				
2061 VERIFY MTL FØR FWD DØME	13	0	0	13
2062 SCRIBE+SAW BLK TØ REQ SHAPE	0	160	320	7.2
2063 SHEAR SPIN FØRM+INSP	0	200	460	9.9
2064 CLEAN+ANNEAL+QUENCH+INSP	0	240	320	8.4
2065 SPIN FØRM TØ SHAPE+INSP	0	300	600	13.5
2066 CLEAN+ANNEAL+QUENCH+INSP	0	240	320	8.4
2067 FINAL FØRM SPIN+STA TRIM+INSP	0	300	600	13.5
2068 CUT+TRIM C/C OPNG+DEBURR+INSP	0	80	260	5.1
2069 CLN+HEAT TREAT+AGE+INSP+STØRE	0	300	540	12.6
2070 MASK+CHEM MILL+DEBURR+INSP	78	900	0	91.5
2071 CLEAN+ANØDIZE+INSP	0	180	270	6.75
2072 WEIGH+STØRE	0	50	90	2.1
2073 WELD JAMB+INSP	2.8	130	180	7.45
2074 WELD STUDS+FITTINGS+INSP	2.2	190	230	8.5
2075 GRIND ALL WELDS+DYE-PEN INSP	0	600	2000	39
2076 PERFØRM LEAK CHECK	1	100	300	7
2077 X-RAY ALL WELDS+WEIGH	3.	950	40	17.85
2078 LD ØN TRNSPR+MØVE F/D TØ A/A	0	60	120	2.7
	1369.7	39260	72930	3052.55
LABØR CØST (K$)		(588.9)	(1093.95)	

SUMMARY ØF RESULTS

	MAT'L CØST (K$)	Q.C. LABØR (M/HR)	MFG. LABØR (M/HR)	PRE-MFG. LABØR (M/HR)	TØTAL CØST (K$)
TØØLING					3395.7
FACILITIES					6972
PRE-MANUFACTURING					
NØN-RECURRING CØST				64540.	968.1
RECURRING CØST				10000	150
MFG. PRØCESSES	1369.7	39260	72930		3052.55
	1369.7	39260	72930	74540.	14538.4
LABØR IN (K$)		(588.9)	(1093.95)		

Table 5-19

Manufacturing Cost Analysis

MANUFACTURING CØST ANALYSIS
09/23/70

LINE: IMPRØVED MANUFACTURING LINE (LINE 2)

STRUCTURE: PRØPELLANT TANK STRUCTURE (ELEMENT 2)

PRØDUCTIØN RATE: 20 PER YEAR

VARIATIØN FRØM THE NØMINAL: NØNE

TØTAL PRØGRAM LENGTH: 5 YEARS

LABØR RATES-($/HR): PRE-MFG.- 15. ; Q.C.- 15. ; MFG.- 15.

TØØLING	UNIT CØST (K$)	NØ. UNITS	TØTAL CØST (K$)
100 PØWER SAW	8	3	24
101 WØRK PLATFØRM	2	3	6
102 SCRIBE ARM	1	3	3
120 LATHE FIXTURE # 1	12	1	12
121 LATHE FIXTURE # 2	12	1	12
122 LATHE FIXTURE # 3	12	1	12
130 SPINNING MILL-PØWER SHEAR-(NUM. CØNTR.)	3250	1	3250
140 HEAT TREAT ØVEN (25'X25'X40')	350	2	700
141 QUENCH TANK (25'X25'X40')	100	1	100
150 DØME RØTATING TØØL	125	1	125
151 ETCH CLEANING TANK (25'X25'X12')	50	1	50
152 ETCH CLEANING TANK (25'X25'X40')	100	1	100
160 JAMB RING WELDER STAND	30	2	60
161 JAMB CLAMPS	2	2	4
162 JAMB RING/DØLLAR ØPENING TRIMMER	5	2	10
163 JAMB RING/DØLLAR WELDER	7	2	14
164 X-RAY UNIT	18	2	36
170 SPRAY BØØTH	20	1	20
171 NEØPRENE MASKANT SPRAY	4	1	4
172 MASKANT CUT STENCIL # 1	1	8	8
173 MASKANT CUT STENCIL # 2	1	8	8
174 MASKANT CUT STENCIL # 3	1	8	8
175 MASKANT CUT STENCIL # 4	1	8	8
180 CHEM MILL (25'X25'X12')	75	2	150
190 ANØDIZE (25'X25'X40')	75	4	300
200 LØAD CELL # 1	2	1	2
201 HØIST SPREADER BAR #1	0.8	1	0.8
202 HØIST SPREADER BAR #2	0.8	1	0.8
203 HØIST SPREADER BAR #3	0.8	1	0.8
204 PICKUP PØSITIØNER	7	2	14
205 STUD WELDER HEAD	10	2	20
210 WELD GRINDER(PØRTABLE)	1	6	6
220 AMMØNIA GAS PRESSURE TEST RIG	10	4	40
230 X-RAY HØLDING FIXTURE	15	4	60
231 X-RAY UNIT	18	4	72
240 TRANSPØRT FIXTURE	4	6	24
250 DØME TØ RING WELD FIXTURE	12	1	12
251 WELDING HEAD	18	1	18
252 X-RAY UNIT	18	1	18
260 STRETCH PRESS	20	1	20
261 RING DIE #1	2	1	2
262 RING DIE #2	2	1	2
263 RING DIE #3	2	1	2
270 RING EXTRUSIØN CUTTER	0.5	1	0.5
271 RING WELD FIXTURE	20	1	20
272 RING WELD FIXTURE SET 1	1	1	1
273 RING WELD FIXTURE SET 2	1	1	1
274 WELDING HEAD	10	1	10
280 BØNDING GANTRY	40	4	160
281 HEAT/PRESSURE DØME	80	4	320
282 VACUUM BAG	8	4	32
283 BLEEDER CLØTH	2	4	8
284 VACUUM PUMP	2	4	8
285 SØNIC MEASURING DEVICE& AUTØ RDØUT	25	4	100
290 CØMMØN BULKH RING BUTT WLD FIXT	8	2	16
291 WELDING HEAD	18	2	36
300 CØM BULKH LATHE FIXTURE	12	1	12
301 RING CUTTING TØØL	1	1	1
310 SPREADER BARS(HØIST)	1	2	2
311 LØAD CELL	2	2	4
320 LØX TANK WELD FIXTURE	35	3	105
321 DRILL	1	3	3
322 DRILL JIG	2	3	6
323 WELDER	18	3	54
330 SKIN MILL(10'X40')	500	1	500
340 DRILL TEMPLATE	0.5	4	2
341 PØWER DRILL	1	4	4
350 BRAKE-40'	150	1	150
360 SEGMENT TRIM FIXTURE	35	2	70
361 PØWER CUTTER	5	2	10
370 SPREADER BARS	0.2	28	5.6
371 LØNGITUDINAL WELD FIXTURE	45	2	90
372 WELDER HEAD	18	2	36
380 END TRIM/RING WELD DØLLY	75	2	150
381 WELD FIXTURE	5	2	10
382 WELDER HEAD	18	2	36
410 X-RAY UNIT	18	1	18
420 HØIST SPREADER BAR	1.5	4	6
421 LØAD CELL	2	2	4
430 TANK ASSEM TØWER	200	6	1200
431 HEAT BLANKET	12	6	72
432 WELDER HEAD	18	6	108
433 X-RAY UNIT	18	6	108
434 HØISTING YØKE & CRANE	50	6	300
440 HYDRØSTATIC TEST EQUIP	100	6	600
441 DEGREASER	80	6	480
450 TANK DØLLY	40	6	240
451 HØIST YØKE	10	6	60
452 LØAD CELL	2	6	12
TØTAL TØØLING CØST (K$)			10509.5

FACILITIES	TØTAL CØST (K$)
500 CØNSØLIDATED MANUFACTURING & ASSEMBLY PLANT	16680

NEAR-TERM PRE-MANUFACTURING ØPERATIØNS

ITEM	M/HRS	TØTAL CØST (K$)
NØN-RECURRING CØSTS		
800 REVIEW PRØGRAM DIRECTIVES	700.	10.5
810 MFG. PRELIMINARY SCHEDULES	700.	10.5
820 PRØDUCIBILITY STUDIES	9380.	140.7
830 IDENTIFY/ØRDER LØNG LEAD ITEMS	1890.	28.35
840 ACCUMULATE/REVIEW ENGR & QC DØCUMENT.	1890.	28.35
850 DEVELØP SUB-ASSEMBLY & PARTS SCHEDULE	9380.	140.7
860 MFG. PLANNING ØPERATIØNS	14000.	210
870 DESIGN/PRØCURE TØØLING	22400.	336
880 VENDØR EVALUATIØN & SELECTIØN	4200.	63
NØN-RECURRING TØTALS	64540.	968.1
RECURRING CØSTS		
900 EXPEDITE IN-HØUSE/PURCHASE PARTS	80000.	1200
910 REVIEW PRØGRESS WITH PRØGRAM ØFFICE	20000.	300
RECURRING TØTALS	100000	1500
TØTAL RECURRING AND NØN-RECURRING PRE-MFG. CØSTS=		2468.1

MANUFACTURING PRØCESSES	MAT'L CØST (K$)	Q.C. LABØR (M/HR)	MFG. LABØR (M/HR)	TØTAL CØST (K$)
1000 TANK ASSEMBLY				
1001 INSPECT FWD DØME	0	2000	1000	45
1002 INSPECT LØX TANK	0	4000	1000	75
1003 MØVE F/D+L/T TØ ASSY TØWER	0	0	2000	30
1004 WELD CYL TØ L/T(INTER)+INSP	62.	11200	17200	488
1005 WELD CYL TØ L/T(EXTER)+INSP	62.	5200	5200	218
1006 WELD CYL TØ F/D(INTER)+INSP	62.	11200	14200	443
1007 WELD CYL TØ F/D(EXTER)+INSP	62.	10200	10200	368
1008 HYDRØSTATIC TEST	0	20000	40000	900
1009 DEGREASE	0	5000	10000	225
1010 WEIGH+STØRE	0	2000	12500	217.5
1020 LØX TANK ASSEMBLY				
1021 MATE C/B+A/D:SEAL WELD+INSP	198.	15600	16000	672
1022 X-RAY ALL WELDS+WEIGH	28.	2000	4000	118
1023 MØVE TØ A/A	0	500	1000	22.5
1030 AFT DØME ASSY				
1031 VERIFY MTL FØR A/D	260	0	0	260
1032 SCRIBE+SAW BLK TØ REQ SHAPE	0	1600	3200	72
1033 SHEAR SPIN FØRM+INSP	0	2000	4600	99
1034 CLEAN+ANNEAL+QUENCH+INSP	0	2400	3200	84
1035 SPIN FØRM TØ SHAPE+INSP	0	3000	6000	135
1036 CLEAN+ANNEAL+QUENCH+INSP	0	2400	3200	84
1037 FINAL FØRMSPIN+STA TRIM+INSP	0	3000	6000	135
1038 CUT+TRIM C/C ØPNG+DEBURR+INSP	0	800	2600	51
1039 CLN+HEAT TREAT+AGE+INSP+STØRE	0	3000	5400	126
1040 MASK+CHEM MILL+DEBURR+INSP	780.	9000	0	915
1041 CLEAN+ANØDIZE+INSP	0	1800	2700	67.5
1042 WEIGH+STØRE	0	500	900	21
1043 WELD JAMB+INSP	28.	1300	1800	74.5
1044 WELD STUDS+FITTINGS+INSP	22	1900	2300	85
1045 GRIND ALL WELDS+DYE-PEN INSP	0	6000	20000	390
1046 PERFØRM LEAK CHECK	10	1000	3000	70
1047 X-RAY ALL DØME WELDS+WEIGH	30.	9500	400	178.5
1048 TRANSPØRT TØ L/T A/A	0	500	1000	22.5
1050 CØMMØN BULKHEAD ASSY				
1051 ETCH CLEAN AFT DØME	20	1500	3000	87.5
1052 ETCH CLEAN FWD DØME	20	1500	3000	87.5
1053 FIT+BØND HØNEYCØMB+INSP	380	40000	160000	3380
1054 BUTT WELD Y RINGS+LK CK+INSP	64.	2200	4200	160
1055 MACHINE RING BUTT WELDS	0	2000	8000	150
1056 X-RAY WELD+U/I DØME+WGH+STØRE	424.	3000	1000	484
1060 CØMMØN BULKHEAD F/D				
1061 VERIFY MTL FØR C/B F/D	80	0	0	80
1062 SCRIBE+SAW BLK TØ REQ SHAPE	0	1600	3200	72
1063 SHEAR SPIN FØRM+INSP	0	2000	4600	99
1064 CLEAN+ANNEAL+QUENCH+INSP	0	2400	3200	84
1065 SPIN FØRM TØ SHAPE+INSP	0	3000	6000	135
1066 CLEAN+ANNEAL+QUENCH+INSP	0	2400	3200	84
1067 FINAL FØRM SPIN+STA TRIM+INSP	0	3000	6000	135
1068 CUT+TRIM C/C ØPNG+DEBURR+INSP	0	800	2600	51
1069 CLN+HEAT TREAT+AGE+INSP+STØRE	0	3000	5400	126
1070 MASK+CHEM MILL+DEBURR+INSP	380	9000	0	515
1071 CLEAN+ANØDIZE+INSPECT	0	2700	3600	94.5
1072 WELD DØME TØ RING+INSP	64.	2600	3400	154
1073 WELD CENTER CAP TØ DØME+INSP	28.	1300	2000	77.5
1074 GRIND ALL WELDS+DYE-PEN INSP	0	6000	20000	390
1075 X-RAY ALL WELDS	23.	0	0	23
1076 PERFØRM LEAK CHECK+WGH+STØRE	10	1500	4000	92.5
1080 RING:F/D:CØMMØN BULKHEAD				
1081 VERIFY MTL FØR 1 F/D Y RING	35	0	0	35
1082 FØRM+INSP	0	1400	2600	60
1083 TRIM+CLEAN+AGE+INSP	0	400	1400	27
1084 ANØDIZE+WEIGH+STØRE	0	400	800	18
1085 WELD SEG+STRAIGHTEN RING+INSP	0	4000	8000	180
1086 MILL RING FACE+INSP+STØRE	0	2500	5000	112.5
1090 CØMMØN BULKHEAD AFT DØME				
1091 VERIFY MTL FØR C/B AFT DØME	0	0	0	0
1092 SCRIBE+SAW BLK TØ REQ SHAPE	0	1600	3200	72
1093 SHEAR SPIN FØRM+INSP	0	2000	4600	99
1094 CLEAN+ANNEAL+QUENCH+INSP	0	2400	3200	84
1095 SPIN FØRM TØ SHAPE+INSP	0	3000	6000	135
1096 CHEAN+ANNEAL+QUENCH+INSP	0	2400	3200	84
1097 FINAL FØRM SPIN+STA TRIM+INSP	0	3000	6000	135
1098 CUT+TRIM C/C ØPNG+DEBURR+INSP	0	800	2600	51
1099 CLN+HEAT TREAT+AGE+INSP+STØRE	0	3000	5400	126
1100 MASK+CHEM MILL+DEBURR+INSP	320	9000	0	455
1110 CLEAN+ANØDIZE+INSP	0	2700	3600	94.5
1111 WELD DØME TØ RING+INSP	64.	2600	3400	154
1112 WELD CENTER CAP TØ DØME+INSP	28.	1300	2000	77.5
1113 GRIND ALL WELDS+DYE-PEN INSP	0	6000	20000	390
1114 X-RAY ALL WELDS	46.	0	0	46
1115 PERFØRM LEAK CHECK+WGH+STØRE	10	1500	4000	92.5
2010 RING:A/D:CØMMØN BULKHEAD				
2011 VERIFY MTL FØR 1 A/D Y RING.	35	0	0	35
2012 FØRM+INSP	0	1400	2600	60
2013 TRIM+CLEAN+AGE+INSP	0	400	1400	27
2014 ANØDIZE+WEIGH+STØRE	0	400	800	18
2015 WELD SEG+STRAIGHTEN RING+INSP	0	4000	8000	180
2016 MILL RING FACE+INSP+STØRE	0	2500	5000	112.5
2020 TANK CYLINDER				
2021 VERIFY MTL FØR 7 TANK SEG(S)	3100	0	0	3100
2022 MILL EDGES	650	2800	5600	776
2023 MILL WAFFLE PATTERN	3250	2800	5600	3376
2024 ULTRASØNIC INSP	1385.	0	0	1385
2025 MØVE SEG(S) TØ A/A	0	700	1400	31.5
2027 DRILL SPREADER BAR HØLES	0	1400	2800	63
2029 HEAT TREAT(ANNEAL)	0	0	1400	21
2030 FØRM 7 SKINS+CLN+AGE+INSP	0	9800	20300	451.5
2031 ANØDIZE+TRIM+WGH+INSTL S/B(S)	0	3100	4500	114
2041 WELD SEG(S)+INSP	220.	10600	21200	697
2043 TRIM CYL+WELD RINGS	127	3400	6600	277
2044 X-RAY ALL WELDS+WEIGH+STØRE	260	2000	8000	410
2050 RING TANK CYL				
2051 VERIFY MTL FØR 2 RINGS(CYL)	70	0	0	70
2052 FØRM 8 SEG(S)+INSP	0	2800	5200	120
2053 TRIM+AGE+INSP	0	800	2800	54
2054 ANØDIZE+WEIGH+STØRE	0	800	1600	34
2055 WELD SEG+STRTN RINGS+INSP	0	8000	16000	360
2056 MILL RING FACE+INSP+WEIGH	0	4500	9000	202.5
2057 MØVE RINGS TØ A/A	0	500	1000	22.5
2060 FWD DØME				
2061 VERIFY MTL FØR FWD DØME	130	0	0	130
2062 SCRIBE+SAW BLK TØ REQ SHAPE	0	1600	3200	72
2063 SHEAR SPIN FØRM+INSP	0	2000	4600	99
2064 CLEAN+ANNEAL+QUENCH+INSP	0	2400	3200	84
2065 SPIN FØRM TØ SHAPE+INSP	0	3000	6000	135
2066 CLEAN+ANNEAL+QUENCH+INSP	0	2400	3200	84
2067 FINAL FØRM SPIN+STA TRIM+INSP	0	3000	6000	135
2068 CUT+TRIM C/C ØPNG+DEBURR+INSP	0	800	2600	51
2069 CLN+HEAT TREAT+AGE+INSP+STØRE	0	3000	5400	126
2070 MASK+CHEM MILL+DEBURR+INSP	780.	9000	0	915
2071 CLEAN+ANØDIZE+INSP	0	1800	2700	67.5
2072 WEIGH+STØRE	0	500	900	21
2073 WELD JAMB+INSP	28.	1300	1800	74.5
2074 WELD STUDS+FITTINGS+INSP	22	1900	2300	85
2075 GRIND ALL WELDS+DYE-PEN INSP	0	6000	20000	390
2076 PERFØRM LEAK CHECK	10	1000	3000	70
2077 X-RAY ALL WELDS+WEIGH	30.	9500	400	178.5
2078 LD ØN TRNSPR+MØVE F/D TØ A/A	0	600	1200	27
	13697	392600	729300	30525.5
LABØR CØST (K$)		(5889)	(10939.5)	

SUMMARY ØF RESULTS

	MAT'L CØST (K$)	Q.C. LABØR (M/HR)	MFG. LABØR (M/HR)	PRE-MFG. LABØR (M/HR)	TØTAL CØST (K$)
TØØLING					10509.5
FACILITIES					16680
PRE-MANUFACTURING					
NØN-RECURRING CØST				64540.	968.1
RECURRING CØST				100000	1500
MFG. PRØCESSES	13697	392600	729300		30525.5
	13697	392600	729300	164540.	60183.1
LABØR IN (K$)		(5889)	(10939.5)		

5.3.2 SUPPORT FRUSTUM STRUCTURE (ELEMENT 1)

5.3.2.1 General

Since manufacturing lines actually in place in any one facility are behind the current state of the art, Line 2 represents a hypothetical condition. Therefore, Line 2 for Element 1 represents the implementation of equipment and processes that can yield a delta improvement over Line 1 conditions. A perspective of these changes can be obtained by referring to Table 5-28.

5.3.2.2 Manufacturing Processes and Tooling

The derivation of Line 2 can be best described in the context of the principal structural elements, skin, longeron, etc., and the assembly joining method.

Skin—At the low production rate of two assemblies per year it is doubtful that any change from Line 1 is warranted. The Line for 20 per year, however, anticipates the application of the stretch-form technique now coming into wider use. While requiring specialized equipment and tooling, it is considered that the total of tangible and intangible factors involved would justify this approach.

Longeron—Here also, the production rate of 2 per year would dictate the most straightforward approach to satisfy critical design requirements. This involves the use of three tools/processes: (1) brake-forming, (2) sawing out the lightening notch on a band-saw, and (3) joggling in a press or special-purpose equipment. All of these are conventional operations and do not require special tooling. For the production rate of 20 per year, however, it is expected that design would accommodate to a standard extruded angle or a unique extrusion die and could be justified on the basis of the footage involved. Also, the quantities involved would justify the use of a combination die for joggle, notch, and shear.

Ring—The efficiencies of manufacturing multiple rings from a single forging should be so well established for Line 2 that this approach is incorporated even in the low production rate.

Bulkhead—A significant improvement in adhesive systems or methods of assembly cannot be predicted in order to warrant a change in method from Line 1. Any change here is reserved for Line 3 implementation.

Assembly—The use of roll and spot welding is implemented on Line 2, since it is felt that the important process variables of surface condition and welding cycles can be controlled sufficiently to produce a reliable weld.

5.3.2.3 Cost Considerations

Because of the modest quantities involved, the cost differences from Line 1 are expected to be small. It should be pointed out, however, that side effects of these changes may be more significant than the direct effects. By this, we mean shorter schedules should be achieved, which in turn mean faster response to program changes, and higher reliability of the process itself.

5.3.2.4 Summary

The tool lists, manufacturing process planning, and cost summaries for both 2 per year and 20 per year lines appear in Tables 5-20 and 5-21.

5.4 DESCRIPTION, ADVANCED MANUFACTURING LINE, LINE 3

5.4.1 PROPELLANT TANK STRUCTURE (ELEMENT 2)

5.4.1.1 General

The Advanced Manufacturing Line, Line 3, incorporates, in addition to the change in Line 2, improved welding techniques for welding cylinder segments, Y rings, cylinder-to-dome rings, jamb rings, and dollar covers. In addition, Line 3, with a production rate of 20 per year, incorporates a cylinder section comprised of four rather than seven segments. Line 3, with a production rate of 2 per year, uses the same cylinder configuration as Lines 1 and 2.

5.4.1.2 Manufacturing Processes and Methods

The manufacturing processes of Line 3, both production rates, reflect improved welding techniques estimated to reduce welding time, quality control time for weld checking, and weld X-ray time by 50 percent. In addition, Line 3, with a production rate of 20 per year, reflects the deletion of 105 feet of weld per cylindrical section by changing the cylinder from seven to four segments. The defined and sequenced manufacturing processes along with estimated material cost and manpower requirements per tank are shown in Table 5-22 for a production rate of 2 per year.

Table 5-20

Manufacturing Cost Analysis, 2 Per Year, Line 2, Element 1

MANUFACTURING CØST ANALYSIS

09/28/70

LINE: IMPRØVED MANUFACTURING LINE (LINE 2)

STRUCTURE: SUPPØRT FRUSTUM STRUCTURE (ELEMENT 1)

PRØDUCTIØN RATE: 2 PER YEAR

VARIATIØN FRØM THE NØMINAL: NØNE

TØTAL PRØGRAM LENGTH: 5 YEARS

LABØR RATES-($/HR): PRE-MFG.- 15. ; Q.C.- 15. ; MFG.- 15.

TØØLING	UNIT CØST (K$)	NØ. UNITS	TØTAL CØST (K$)
100 CØNTRØL MASTER FIXTURE	5	2	10
102 MASTER DRILL FIXTURE	5	2	10
104 DRILL FIXTURES	5	2	10
106 INSERT LØCATING FIXTURES	2	2	4
108 BULKHEAD ASSEMBLY FIXTURES	3	2	6
110 CHEM CLEANING TANKS	15	1	15
120 SPØT WELDER	45	1	45
122 RØLL-SPØT ELECTRØDE	0.075	1	0.075
130 TESTING MACHINE	24	1	24
132 TEST FIXTURE	0.075	1	0.075
140 WELD ASSEMBLY FIXTURE	3	1	3
150 SPØT WELD TEST FIXTURE B	0.075	1	0.075
152 SPØT WELD ELECTRØDE B	0.075	1	0.075
156 TØRQUE TØØLS AND WRENCH SET	0.15	1	0.15
160 INSPECTIØN STATIØN	0.5	1	0.5
172 MECHANICAL PRESS	10	1	10
190 SHEAR	18	1	18
200 BAND SAW	0.4	1	0.4
202 APPLIED TEMPLATE	0.065	1	0.065
210 BRAKE	12	1	12
212 JØGGLE DIES	0.05	1	0.05
220 HAND DRILL	0.05	1	0.05
222 TEMPLATE	0.08	1	0.08
230 METAL TAG STAMP	0.01	1	0.01
240 RING HØLDING FIXTURE	0.3	1	0.3
243 BØRING MILL	40	1	40
244 CUTTING TØØLS	0.05	1	0.05
250 RING FINISH HØLDING FIXTURE	0.3	1	0.3
260 MICRØMETER	0.05	1	0.05
261 HEIGHT GAGE	0.05	1	0.05
262 INDICATØR	0.05	1	0.05
270 RØUGHNESS GAGE	0.04	1	0.04
280 WEIGH SCALE	0.5	1	0.5
290 SKIN INSPECTIØN STATIØN	0.3	1	0.3
301 LAYØUT TEMPLATE	0.065	1	0.065
303 BENCH	0.1	1	0.1
310 RØLL FØRMER	8	1	8
312 CØNTØUR TEMPLATE	0.065	1	0.065
360 WØRK STAND	0.1	1	0.1
361 APPLIED TEMPLATE	0.065	1	0.065
362 HAND DRILL	0.05	1	0.05
363 PUNCHES	0.02	1	0.02
364 APPLIED TEMPLATE	0.065	1	0.065
380 DØLLY	0.2	1	0.2
TØTAL TØØLING CØST (K$)			218.975

FACILITIES	TØTAL CØST (K$)
500 CØNSØLIDATED MANUFACTURING & ASSEMBLY PLANT	620

MANUFACTURING PRØCESSES	MAT'L CØST (K$)	Q.C. LABØR (M/HR)	MFG. LABØR (M/HR)	TØTAL CØST (K$)
1000 FRUSTUM ASSEMBLY				
1001 PURCHASE 1 RING	10	0	0	10
1002 PURCHASE 1 BULKHEAD	100	0	0	100
1003 VERIFY, INSP, CLEAN, BAG PARTS	0.2	40	60	1.7
1004 MAKE RØLL-SPØT SPEC, INSPECT	0.5	30	20	1.25
1005 LØAD INTERF. RING&SKIN IN FIXT	0	0	20	0.3
1006 RØLL-SPØT ASSEMBLE & INSP	0	10	20	0.45
1007 LØAD FWD RING, RØLL-SPØT	0	0	40	0.6
1008 MAKE SPØT-WELD TESTS, INSP	0.1	30	10	0.7
1009 SPØT WELD LØNG. SPL&DBLRS, INSP	0	40	60	1.5
1010 BØLT ASSEMBLE BULKHEAD	0	0	20	0.3
1011 CLEAN, IDENTIFY, INSPECT	0	20	20	0.6
1020 LØNGERØN				
1021 VERIFY MATERIAL	0.16	16	0	0.4
1022 SHEAR TØ SIZE	0	0	16	0.24
1023 SAW NØTCH	0	0	32	0.48
1024 BRAKE FØRM 8 JØGGLE, INSP	0	16	32	0.72
1025 DRILL PER TEMPLATE	0	0	32	0.48
1026 DEBURR, CLEAN, ALØD, IDENT, INSP	0	16	32	0.72
1030 RING				
1031 VERIFY MATERIAL	0.3	30	0	0.75
1032 FACE & FØRM GRØØVE	0	0	32	0.48
1033 FACE BØRE, SEMI-FIN, CUT ØFF	0	0	85	1.275
1034 REVERSE RING, SEMI-FINISH, AGE	0	0	60	0.9
1035 RE-SETUP, FINISH 1 SIDE, INSP	0	10	23	0.495
1036 REVERSE & FIN. CØMPLETE, INSP	0	20	60	1.2
1037 DEBURR, CLEAN, & ALØDINE	0.1	0	36	0.64
1038 WEIGH, IDENTIFY, INSP	0	10	10	0.3
1040 SKIN				
1041 VERIFY MATERIAL	0.6	8	0	0.72
1042 TRIM TØ LAYØUT	0	0	20	0.3
1043 RØLL FØRM	0	0	24	0.36
1044 DRILL HØLES PER TEMPLATE	0	0	52	0.78
1045 TRIM ØUTLINE, DEBURR, INSPECT	0	12	68	1.2
1046 CHEM CLEAN, ALØDINE	0.6	0	12	0.78
1047 TAG PART	0	0	8	0.12
1048 APPLY PRØTECTIØN, LØAD, INSP	0.2	8	8	0.44
	112.76	316	912	131.18
LABØR CØST (K$)		(4.74)	(13.68)	

NEAR-TERM PRE-MANUFACTURING ØPERATIØNS

NØN-RECURRING CØSTS

ITEM	M/HRS	TØTAL CØST (K$)
800 REVIEW PRØGRAM DIRECTIVES	700.	10.5
810 MFG. PRELIMINARY SCHEDULES	420.	6.3
820 PRØDUCIBILITY STUDIES	700.	10.5
830 IDENTIFY/ØRDER LØNG LEAD ITEMS	500.	7.5
840 ACCUMULATE/REVIEW ENGR & QC DØCUMENT.	1120.	16.8
850 DEVELØP SUB-ASSEMBLY & PARTS SCHEDULE	528.	7.92
860 MFG. PLANNING ØPERATIØNS	3200.	48
870 DESIGN/PRØCURE TØØLING	1400.	21
880 VENDØR EVALUATIØN & SELECTIØN	1120.	16.8
NØN-RECURRING TØTALS	9688	145.32

RECURRING CØSTS

ITEM	M/HRS	TØTAL CØST (K$)
900 EXPEDITE IN-HØUSE/PURCHASE PARTS	2750.	41.25
910 REVIEW PRØGRESS WITH PRØGRAM ØFFICE	550.	8.25
RECURRING TØTALS	3300	49.5

TØTAL RECURRING AND NØN-RECURRING PRE-MFG. CØSTS= 194.82

SUMMARY ØF RESULTS

	MAT'L CØST (K$)	Q.C. LABØR (M/HR)	MFG. LABØR (M/HR)	PRE-MFG. LABØR (M/HR)	TØTAL CØST (K$)
TØØLING					218.975
FACILITIES					620
PRE-MANUFACTURING					
NØN-RECURRING CØST				9688	145.32
RECURRING CØST				3300	49.5
MFG. PRØCESSES	112.76	316	912		131.18
	112.76	316	912	12988	1164.98
LABØR IN (K$)		(4.74)	(13.68)		

Table 5-21

Manufacturing Cost Analysis

MANUFACTURING CØST ANALYSIS
****
09/28/70

LINE: IMPRØVED MANUFACTURING LINE (LINE 2)

STRUCTURE: SUPPØRT FRUSTUM STRUCTURE (ELEMENT 1)

PRØDUCTIØN RATE: 20 PER YEAR

VARIATIØN FRØM THE NØMINAL: NØNE

TØTAL PRØGRAM LENGTH: 5 YEARS

LABØR RATES-($/HR): PRE-MFG.- 15. ; Q.C.- 15. ; MFG.- 15.

TØØLING	UNIT CØST (K$)	NØ. UNITS	TØTAL CØST (K$)
100 CØNTRØL MASTER FIXTURE	5	2	10
102 MASTER DRILL FIXTURE	5	2	10
104 DRILL FIXTURES	5	2	10
106 INSERT LØCATING FIXTURES	2	2	4
108 BULKHEAD ASSEMBLY FIXTURES	3	2	6
110 CHEM CLEANING TANKS	15	1	15
120 SPØT WELDER	45	1	45
122 RØLL-SPØT ELECTRØDE	0.075	1	0.075
130 TESTING MACHINE	24	1	24
132 TEST FIXTURE	0.075	1	0.075
140 WELD ASSEMBLY FIXTURE	3	1	3
150 SPØT WELD TEST FIXTURE B	0.075	1	0.075
152 SPØT WELD ELECTRØDE B	0.075	1	0.075
156 TØRQUE TØØLS AND WRENCH SET	0.15	1	0.15
160 INSPECTIØN STATIØN	0.5	1	0.5
170 JØGGLE-NØTCH-SHEAR	2	1	2
172 MECHANICAL PRESS	10	1	10
180 PUNCH DIE	0.8	1	0.8
230 METAL TAG STAMP	0.01	1	0.01
242 RING HØLDING FIXTURE	0.5	1	0.5
243 BØRING MILL	40	1	40
244 CUTTING TØØLS	0.05	1	0.05
250 RING FINISH HØLDING FIXTURE	0.3	1	0.3
260 MICRØMETER	0.05	1	0.05
261 HEIGHT GAGE	0.05	1	0.05
262 INDICATØR	0.05	1	0.05
270 RØUGHNESS GAGE	0.04	1	0.04
280 WEIGH SCALE	0.5	1	0.5
290 SKIN INSPECTIØN STATIØN	0.3	1	0.3
300 TABLE	0.3	1	0.3
301 LAYØUT TEMPLATE	0.065	1	0.065
302 ELECTRIC SHEARS	0.1	1	0.1
310 RØLL FØRMER	8	1	8
320 ARC WELDER	2	1	2
322 WELD FIXTURE	2	1	2
330 STRETCH MANDREL	3	1	3
340 BØRING MILL FIXTURE	0.8	1	0.8
350 INSPECTIØN FIXTURE	1	1	1
380 DØLLY	0.2	1	0.2
TØTAL TØØLING CØST (K$)			200.065

MANUFACTURING PRØCESSES	MAT'L CØST (K$)	Q.C. LABØR (M/HR)	MFG. LABØR (M/HR)	TØTAL CØST (K$)
1000 FRUSTUM ASSEMBLY				
1001 PURCHASE 1 RING	75	0	0	75
1002 PURCHASE 1 BULKHEAD	400	0	0	400
1003 VERIFY,INSP,CLEAN,BAG PARTS	2.	400	600	17
1004 MAKE RØLL-SPØT SPEC,INSPECT	5	300	200	12.5
1005 LØAD INTERF. RING&SKIN IN FIXT	0	0	200	3
1006 RØLL-SPØT ASSEMBLE & INSP	0	100	200	4.5
1007 LØAD FWD RING, RØLL-SPØT	0	0	400	6
1008 MAKE SPØT-WELD TESTS,INSP	1.	300	100	7
1009 SPØT WELD LØNG.SPL&DBLRS,INSP	0	400	600	15
1010 BØLT ASSEMBLE BULKHEAD	0	0	200	3
1011 CLEAN,IDENTIFY,INSPECT	0	200	200	6
1020 LØNGERØN				
1021 VERIFY MATERIAL	1.6	160	0	4
1022 JØGGLE	0	0	48	0.72
1023 NØTCH	0	0	48	0.72
1024 SHEAR	0	0	64	0.96
1025 PUNCH HØLES	0	0	160	2.4
1026 DEBURR,CLEAN,ALØD,IDENT,INSP	0	160	320	7.2
1030 RING				
1031 VERIFY MATERIAL	3.	300	0	7.5
1032 FACE & FØRM GRØØVE	0	0	320	4.8
1033 FACE BØRE,SEMI-FIN,CUT ØFF	0	0	850	12.75
1034 REVERSE RING,SEMI-FINISH,AGE	0	0	600	9
1035 RE-SETUP,FINISH 1 SIDE,INSP	0	100	230	4.95
1036 REVERSE & FIN. CØMPLETE,INSP	0	200	600	12
1037 DEBURR,CLEAN, & ALØDINE	1.	0	360	6.4
1038 WEIGH,IDENTIFY,INSP	0	100	100	3
1040 SKIN				
1041 VERIFY MATERIAL	15.	20	0	15.3
1042 TRIM TØ LAYØUT	0	0	50	0.75
1043 RØLL FØRM	0	0	60	0.9
1044 ARC WELD	0	0	100	1.5
1045 STRETCH FØRM	0	0	150	2.25
1046 TRIM TØ SIZE, INSPECT	0	50	150	3
1047 CHEM CLEAN, ALØDINE	1.5	0	50	2.25
1048 IDENTIFY,PRØTECT,STØRE,INSP	0	20	50	1.05
	505.1	2810	7010	652.4
LABØR CØST (K$)		(42.15)	(105.15)	

FACILITIES	TØTAL CØST (K$)
500 CØNSØLIDATED MANUFACTURING & ASSEMBLY PLANT	620

NEAR-TERM PRE-MANUFACTURING ØPERATIØNS

NØN-RECURRING CØSTS

ITEM	M/HRS	TØTAL CØST (K$)
800 REVIEW PRØGRAM DIRECTIVES	700.	10.5
810 MFG. PRELIMINARY SCHEDULES	420.	6.3
820 PRØDUCIBILITY STUDIES	700.	10.5
830 IDENTIFY/ØRDER LØNG LEAD ITEMS	500.	7.5
840 ACCUMULATE/REVIEW ENGR & QC DØCUMENT.	1120.	16.8
850 DEVELØP SUB-ASSEMBLY & PARTS SCHEDULE	528.	7.92
860 MFG. PLANNING ØPERATIØNS	3200.	48
870 DESIGN/PRØCURE TØØLING	1400.	21
880 VENDØR EVALUATIØN & SELECTIØN	1120.	16.8
NØN-RECURRING TØTALS	9688	145.32

RECURRING CØSTS

ITEM	M/HRS	TØTAL CØST (K$)
900 EXPEDITE IN-HØUSE/PURCHASE PARTS	27500.	412.5
910 REVIEW PRØGRESS WITH PRØGRAM ØFFICE	5500.	82.5
RECURRING TØTALS	33000	495

TØTAL RECURRING AND NØN-RECURRING PRE-MFG. CØSTS= 640.32

SUMMARY ØF RESULTS

	MAT'L CØST (K$)	Q.C. LABØR (M/HR)	MFG. LABØR (M/HR)	PRE-MFG. LABØR (M/HR)	TØTAL CØST (K$)
TØØLING					200.065
FACILITIES					620
PRE-MANUFACTURING					
NØN-RECURRING CØST				9688	145.32
RECURRING CØST				33000	495
MFG. PRØCESSES	505.1	2810	7010		652.4
	505.1	2810	7010	42688	2112.79
LABØR IN (K$)		(42.15)	(105.15)		

Table 5-22

Manufacturing Processes for Propellant Tank Structure (Element 2)
Advanced Manufacturing Line (Line 3)

MANUFACTURING PROCESSES	MAT'L COST (K$)	Q.C. LABOR (M/HR)	MFG. LABOR (M/HR)	TOTAL COST (K$)
1000 TANK ASSEMBLY				
1001 INSPECT FORWARD DOME	0	20	10	0.45
1002 INSPECT LOX TANK	0	40	10	0.75
1003 MOVE DOME&LX TK TO ASM TWR	0	0	20	0.3
1004 WELD CYL TO LX TK(INT)&INSP	0.31	62	122	3.07
1005 WELD CYL TO LX TK(EXT)&INSP	0.31	27	27	1.12
1006 WELD CYL TO FWD DOME(INT)	0.31	62	92	2.62
1007 WELD CYL TO FWD DOME(EXT)	0.31	52	52	1.87
1008 HYDROSTATIC TEST	0	200	400	9
1009 DEGREASE	0	50	100	2.25
1010 WEIGHT & STORE	0	20	125	2.175
1020 LOX TANK ASSEMBLY				
1021 MATE C BLK/A-DOM:SEAL & INSP	1.34	140	152	5.72
1022 X-RAY ALL WELDS, WEIGH	0.14	10	20	0.59
1023 MOVE TO ASSEMBLY AREA	0	5	10	0.225
1030 AFT DOME ASSEMBLY				
1031 VERIFY MATERIAL FOR AFT DOME	2.6	0	0	2.6
1032 SCRIBE & SAW BLKS TO REQ'D SHAPE	0	16	32	0.72
1033 SHEAR SPIN FORM AND INSPECT	0	20	46	0.99
1034 CLEAN, ANNEAL, QUENCH, & INSPECT	0	24	32	0.84
1035 SPIN FORM TO SHAPE AND INSPECT	0	30	60	1.35
1036 CLEAN, ANNEAL, QUENCH, & INSP.	0	24	32	0.84
1037 FINAL FORM SPIN & INSPECT	0	30	60	1.35
1038 CUT&TRM $-OP'NG, DEBURR & INSP	0	8	26	0.51
1039 CLEAN, H-TREAT, AGE, INSP, & STORE	0	30	54	1.26
1040 MASK, CHEM-MILL, DEBURR & INSP.	7.8	90	0	9.15
1041 CLEAN, ANODIZE, & INSPECT	0	18	27	0.675
1042 WEIGH AND STORE	0	5	9	0.21
1043 WELD JAMB & INSPECT	0.25	10	15	0.625
1044 WELD STUDS, FITTINGS, & INSPECT	0.11	10	15	0.485
1045 GRIND ALL WELDS, &DIE-PEN INSP.	0	60	200	3.9
1046 PERFORM LEAK CHECK	0.1	10	30	0.7
1047 X-RAY ALL WELDS & WEIGH	0.15	50	3	0.945
1048 TRANSPORT TO LOX TANK ASSY AREA	0	5	10	0.225
1050 COMMON BULKHEAD ASSEM				
1051 ETCH CLEAN AFT DOME	0.2	15	30	0.875
1052 ETCH CLEAN FWD DOME	0.2	15	30	0.875
1053 FIT&BND HNYCMB & INSPECT	3.8	400	1600	33.8
1054 BUT WLD Y RNGS LK CHK&INSP	0.4	11	28	0.985
1055 MACHINE RING BUT WELDS	0	20	80	1.5
1056 XRAY WLD, ULT/INSP DOME, WGH & STR	4.17	30	10	4.77
1060 COMMON BLKHD FWD DOME				
1061 VERIFY COM BULKHEAD FWD DOME	0.8	0	0	0.8
1062 SCRIBE & SAW BLK TO REQ'D SHAPE	0	16	32	0.72
1063 SHEAR SPIN FORM & INSPECT	0	20	46	0.99
1064 CLEAN, ANNEAL, QUENCH & INSPECT	0	24	32	0.84
1065 SPIN FORM TO SHAPE & INSPECT	0	30	60	1.35
1066 CLEAN, ANNEAL, QUENCH & INSPECT	0	24	32	0.84
1067 FINAL FORM SPIN & INSPECT	0	30	60	1.35
1068 CUT&TRM $-OP'NG TO SIZ, DEBR&INSP	0	8	26	0.51
1069 CLEAN, H-TREAT, AGE INSP & STORE	0	30	54	1.26

Table 5-22 (Continued)

Manufacturing Processes for Propellant Tank Structure (Element 2)
Advanced Manufacturing Line (Line 3)

1070	MASK, CHEM-MILL, DEBURR & INSPECT	3.8	90	0	5.15
1071	CLEAN, ANØDIZE, & INSPECT	0	27	36	0.945
1072	WELD DØME TØ RING & INSPECT	0.32	18	30	1.04
1073	WELD CNTR $-CAP TØ DØME, INSP	0.14	10	18	0.56
1074	GRIND ALL WELDS & DIE-PEN INSP	0	60	200	3.9
1075	X-RAY ALL WELDS	0.23	0	0	0.23
1076	PERFØRM LEAK CHK, WEIGH & STØRE	0.1	15	40	0.925
1080	RING-FWD DØME-CØMMØN BULK				
1081	VRY MAT FØR 1FWD DØM Y RNG	0.35	0	0	0.35
1082	FØRM & INSPECT	0	14	26	0.6
1083	TRM, CLN, AGE & INSPECT	0	4	14	0.27
1084	ANØDIZE, WEIGH & STØRE	0	4	8	0.18
1085	WLD SEG, STRAIGTEN RNG&INSP	0	20	40	0.9
1086	MILL RNG FACE, INSP&STØRE	0	25	50	1.125
1090	CØMMØN BULKHEAD AFT DØME				
1091	VERIFY CØMMØN BULK AFT DØME MATL	0.9	0	0	0.9
1092	SCRIBE&SAW BLK TØ REQ'D SHAPE	0	16	32	0.72
1093	SHEAR SPIN FØRM & INSPECT	0	20	46	0.99
1094	CLEAN, ANØDIZE, QUENCH, & INSPECT	0	24	32	0.84
1095	SPIN FØRM TØ SHAPE & INSPECT	0	30	60	1.35
1096	CLEAN, ANNEAL, QUENCH, & INSPECT	0	24	32	0.84
1097	FINAL FØRM SPIN & INSPECT	0	30	60	1.35
1098	CUT&TRM $-0P'NG, DEBURR& INSP	0	8	26	0.51
1099	CLEAN, H-TREAT, AGE, INSP & STØRE	0	30	54	1.26
1100	MASK, CHEM-MILL, DEBURR& INSP	3.2	90	0	4.55
1110	CLEAN, ANØDIZE, & INSPECT	0	27	36	0.945
1111	WELD DØME TØ RING & INSPECT	0.32	18	30	1.04
1112	WELD CNTR $-CAP TØ DØME, INSP	0.28	10	18	0.7
1113	GRIND ALL WELDS, DIE-PEN INSP	0	60	200	3.9
1114	X-RAY ALL WELDS	0.23	0	0	0.23
1115	PERFØRM LEAK CHK, WEIGH & STØRE	0.1	15	40	0.925
2010	RING-AFT DØME CØMMØN BULK				
2011	VRFY MAT FØR 1AFT DØME Y RNG	0.35	0	0	0.35
2012	FØRM & INSPECT	0	14	26	0.6
2013	TRIM, CLEAN, AGE & INSPECT	0	4	14	0.27
2014	ANØDIZE, WEIGH & STØRE	0	4	8	0.18
2015	WLD SEG, STRAIGHTEN RNG&INSP	0	20	40	0.9
2016	MILL RNG FACE, INSPECT& STØRE	0	25	50	1.125
2020	TANK CYLINDER				
2021	VRFY MAT'L FØR 7 SEG'S(220" MILL)	31	0	0	31
2022	MILL EDGES	6.5	28	56	7.76
2023	MILL WAFFLE PATTERN	32.5	28	56	33.76
2024	ULTRASØNIC INSPECT	13.85	0	0	13.85
2025	MØVE 7 SEGS TØ ASSY AREA	0	7	14	0.315
2027	DRILL SPREADER BAR HØLES	0	14	28	0.63
2029	HEAT TREAT (ANNEAL)	0	0	14	0.21
2030	FØRM 7 SKINS, CLN, AGE, INSP	0	98	203	4.515
2031	ANDZ, TRM, WGH, INSTL SPR BARS	0	31	45	1.14
2041	WELD 7 SEGMENTS & INSP	1.1	80	160	4.7
2043	TRIM CYL & WELD RINGS	0.62	34	66	2.12
2044	XRAY ALL WLDS, WEIGH &STØRE	1.3	10	40	2.05

Table 5-22 (Continued)

Manufacturing Processes for Propellant Tank Structure (Element 2)
Advanced Manufacturing Line (Line 3)

2050	RING TANK CYL				
2051	VRFY MAT FØR 2 RNGS(CYL)	0.7	0	0	0.7
2052	FØRM 8 SEG & INSPECT	0	28	52	1.2
2053	TRIM, AGE, INSPECT	0	8	28	0.54
2054	ANØDIZE WEIGH & STØRE	0	8	16	0.36
2055	WLD SEG, STRTN 2 RNGS&INSP	0	40	80	1.8
2056	MILL RNG FACE, INSP, WEIGH	0	45	90	2.025
2057	MØVE 2 RINGS TØ ASSEM. AREA	0	5	10	0.225
2060	FØREWARD DØME				
2061	VERIFY MAT'L FØR FWD DØME	1.3	0	0	1.3
2062	SCRIBE&SAW BLK TØ REQ'D SHAPE	0	16	32	0.72
2063	SHEAR SPIN FØRM & INSPECT	0	20	46	0.99
2064	CLEAN, ANNEAL, QUENCH, & INSPECT	0	24	32	0.84
2065	SPIN FØRM TØ SHAPE & INSPECT	0	30	60	1.35
2066	CLEAN, ANNEAL, QUENCH, & INSPECT	0	24	32	0.84
2067	FINAL FØRM SPIN & INSPECT	0	30	60	1.35
2068	CUT&TRM $-ØP'NG, DEBUR&INSP.	0	8	26	0.51
2069	CLEAN, H-TREAT, AGE, INSP & STØRE	0	30	54	1.26
2070	MASK, CHEM-MILL, DEBURR, & INSP.	7.8	90	0	9.15
2071	CLEAN, ANØDIZE, & INSP.	0	18	27	0.675
2072	WEIGH & STØRE	0	5	9	0.21
2073	WELD JAMB & INSPECT	0.25	10	15	0.625
2074	WELD STUDS, FITTINGS, & INSP.	0.11	10	15	0.485
2075	GRIND ALL WELDS, DIE-PEN INSP.	0	60	200	3.9
2076	PERFØRM LEAK CHECK	0.1	10	30	0.7
2077	X-RAY ALL WELDS & WEIGH	0.15	50	3	0.945
2078	LØAD, MØVE DØME TØ ASSY AREA	0	6	12	0.27
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		130.9	3462	6788	284.65
	LABØR CØST (K$)		(51.93)	(101.82)	

5.4.1.3 Tooling

The tooling list, Table 5-23, incorporates the spinning mill for spinning domes on both the 2- and 20-per-year production rate lines and deletes the modified vertical boring mill metal spinning tools. In addition, a larger bed skin mill is incorporated to handle the larger plates of the four segment tank cylinder section.

5.4.1.4 Facilities

Manufacturing and Assembly Plants for the advanced manufacturing line are assumed to be the same as for the improved line (Line 2).

5.4.1.5 Transportation

This is the same as for Line 2.

5.4.1.6 Near-Term Pre-Manufacturing Operation

This is the same as for Line 2.

5.4.1.7 Summary

The cost elements for production rates of 2 and 20 tanks per year discussed in paragraph 5.4.1 are summarized utilizing MANCAN program and are shown in Tables 5-24 and 5-25.

5.4.2 SUPPORT FRUSTUM STRUCTURE (ELEMENT 1)

5.4.2.1 General

Changes in manufacturing methods tend to take place slowly except when there are unusual pressures. However, the progress in many technologies centering about the computer has set the stage for a step-wise improvement in manufacturing. The introduction of the numerically controlled machining centers is a case in point.

Table 5-23

PROPELLANT TANK STRUCTURE (Element 2)

TOOL REQUIREMENTS/APPLICATION/UNIT COST LINE # 3																
TOOL IDENTIFICATION			APPLICATION											*PER TOOL		
			DOME		COMMON BULKHEAD					TANK CYLINDER				PROD		
					DOME		RING									
NO.	NAME	UNIT COST $/K	FWD	AFT	FWD	AFT	FWD	AFT	ASSY	CYL	RING	ASSY	TANK ASSEMBLY	2/YEAR	20/YEAR	ALLOWABLE * SQ. FOOTAGE
100	Power Saw	8.0	X	X	X	X								1	3	
101	Work Platform	2.0	X	X	X	X								1	3	
102	Scribe Arm	1.0	X	X	X	X								1	3	
120	Lathe Fixture No. 1	12.0					X							1	1	
121	Lathe Fixture No. 2	12.0						X						1	1	
122	Lathe Fixture No. 3	12.0									X			1	1	
130	Spinning Mill—Power Shear—NC	3250.0	X	X	X	X								1	1	
140	Heat Treat Oven (25'x25'x40')	350.0	X	X	X	X	X	X		X	X			1	2	
141	Quench Tank (25'x25'x40')	100.0	X	X	X	X	X	X		X	X			1	1	
150	Dome Rotating Tool	125.0			X	X								1	1	
151	Etch Cleaning Tank (25'x25'x12')	50.0			X	X								1	1	
152	Etch Cleaning Tank (25'x25'x40')	100.0	X	X	X	X	X	X		X	X			1	1	
160	Jamb Ring Welder Stand	30.0	X	X	X	X								1	2	
161	Jamb Clamps	2.0	X	X										1	2	
162	Jamb Ring/Dollar Opening Trimmer	5.0	X	X	X	X								1	2	
163	Jamb Ring/Dollar Welder	7.0	X	X	X	X								1	2	
164	X-ray Unit	18.0	X	X	X	X								1	2	
170	Spray Booth	20.0	X	X	X	X								1	1	
171	Neoprene Maskat Spray	4.0	X	X	X	X								1	1	
172	Maskant Cut Stencil No. 1	1.0	X											4	8	
173	Maskant Cut Stencil No. 2	1.0		X										4	8	
174	Maskant Cut Stencil No. 3	1.0			X									4	8	
175	Maskant Cut Stencil No. 4	1.0				X								4	8	
180	Chem Mill (25'x25'x12')	75.0	X	X	X	X								1	2	

NC = Numerically Controlled

Table 5-23 (Continued)

PROPELLANT TANK STRUCTURE (Element 2)

TOOL REQUIREMENTS/APPLICATION/UNIT COST
LINE # 3

TOOL IDENTIFICATION			APPLICATION											*PER TOOL		
			DOME		COMMON BULKHEAD					TANK CYLINDER				PROD		
					DOME		RING									
NO.	NAME	UNIT COST $/K	FWD	AFT	FWD	AFT	FWD	AFT	ASSY	CYL	RING	ASSY	TANK ASSEMBLY	2/YEAR	20/YEAR	ALLOWABLE * SQ. FOOTAGE
190	Anodize (25'x25'x40')	75.0	X	X	X	X	X	X		X	X			2	4	
200	Load Cell No. 1	2.0	X	X	X	X	X	X		X	X			1	1	
201	Hoist Spreader Bar No. 1	.8	X	X	X	X								1	1	
202	Hoist Spreader Bar No. 2	.8					X	X			X			1	1	
203	Hoist Spreader Bar No. 3	.8								X				1	1	
204	Pick-up Positioner	7.0	X	X										1	2	
205	Stud Welder Head	10.0	X	X										1	2	
210	Weld Grinder (Portable)	1.0	X	X	X	X	X	X		X	X			3	6	
220	Ammonia Gas Pressure Test Rig	10.0	X	X	X	X			X					1	4	
230	X-ray Holding Fixture	15.0	X	X	X	X			X					1	4	
231	X-ray Unit	18.0	X	X	X	X			X					1	4	
240	Transport Fixture	4.0	X	X					X					2	6	
250	Dome to Ring Weld Fixture	12.0			X	X								1	1	
251	Welding Head	18.0			X	X								1	1	
252	X-ray Unit	18.0			X	X								1	1	
260	Stretch Press	20.0					X	X			X			1	1	
261	Ring Die No. 1	2.0					X							1	1	
262	Ring Die No. 2	2.0						X						1	1	
263	Ring Die No. 3	2.0									X			1	1	
270	Ring Extrusion Cutter	.5					X	X			X			1	1	
271	Ring Weld Fixture	20.0					X	X			X			1	1	
272	Ring Weld Fixture Set 1	1.0					X	X						1	1	
273	Ring Weld Fixture Set 2	1.0									X			1	1	
274	Welding Head	10.0					X	X			X			1	1	

Table 5-23 (Continued)

PROPELLANT TANK STRUCTURE (Element 2)

TOOL REQUIREMENTS/APPLICATION/UNIT COST
LINE # 3

TOOL IDENTIFICATION			APPLICATION											*PER TOOL		
NO.	NAME	UNIT COST $/K	DOME		COMMON BULKHEAD					TANK CYLINDER			TANK ASSEMBLY	PROD		ALLOWABLE * SQ. FOOTAGE
					DOME		RING									
			FWD	AFT	FWD	AFT	FWD	AFT	ASSY	CYL	RING	ASSY		2/YEAR	20/YEAR	
280	Bonding Gantry	40.0							X					1	4	
281	Heat/Pressure Dome	80.0							X					1	4	
282	Vacuum Bag	8.0							X					1	4	
283	Bleeder Cloth	2.0							X					1	4	
284	Vacuum Pump	2.0							X					1	4	
285	Sonic Measuring Device and Automatic Readout	25.0							X	X				1	4	
290	Common Bulkhead Ring Butt Weld Fixture	8.0							X					1	2	
291	Welding Head	18.0							X					1	2	
300	Common Bulkhead Lathe Fixture	12.0							X					1	1	
301	Ring Cutting Tool	1.0							X					1	1	
310	Spreader Bars (Hoist)	1.0							X					1	2	
311	Load Cell	2.0							X					1	2	
320	LOX Tank Weld Fixture	35.0							X					1	3	
321	Drill	1.0							X					1	3	
322	Drill Jig	2.0							X					1	3	
323	Welder	18.0							X					1	3	
330	Skin Mill (10'x40')	500.0								X				1	-	
331	Skin Mill (18'x40')	1000.0								X				-	1	
340	Drill Template	.5								X				2	4	
341	Power Drill	1.0								X				2	4	
350	Brake—40'	150.0								X				1	1	

Table 5-23 (Continued)

PROPELLANT TANK STRUCTURE (Element 2)

TOOL REQUIREMENTS/APPLICATION/UNIT COST LINE # 3																
TOOL IDENTIFICATION			APPLICATION											*PER TOOL		
NO.	NAME	UNIT COST $/K	DOME		COMMON BULKHEAD					TANK CYLINDER			TANK ASSEMBLY	PROD		ALLOWABLE * SQ. FOOTAGE
					DOME		RING									
			FWD	AFT	FWD	AFT	FWD	AFT	ASSY	CYL	RING	ASSY		2/YEAR	20/YEAR	
360	Segment Trim Fixture (Small)	35.0								X				1	-	
361	Power Cutter	5.0								X				1	2	
362	Segment Trim Fixture (Large)	60.0								X					2	
370	Spreader Bars	.2										X		14	28	
371	Longitudinal Weld Fixture	45.0										X		1	2	
372	Welder Head	18.0										X		1	2	
380	End Trim/Ring Weld Dolly	75.0										X		1	2	
381	Weld Fixture	5.0										X		1	2	
382	Welder Head	18.0										X		1	2	
410	X-ray Unit	18.0										X		1	1	
420	Hoist Spreader Bar	1.5										X		2	4	
421	Load Cell	2.0										X		1	2	
430	Tank Assembly Tower	200.0											X	1	6	
431	Heat Blanket	12.0											X	1	6	
432	Welder Head	18.0											X	1	6	
433	X-ray Unit	18.0											X	1	6	
434	Hoisting Yoke and Crane	50.0											X	1	6	
440	Hydrostatic Test Equipment	100.0											X	1	6	
441	Degreaser	80.0											X	1	6	
450	Tank Dolly	40.0											X	1	6	
451	Hoist Yoke	10.0											X	1	6	
452	Load Cell	2.0											X	1	6	

Table 5-24

Manufacturing Cost Analysis

MANUFACTURING CØST ANALYSIS
****
09/23/70

LINE: ADVANCED MANUFACTURING LINE (LINE 3)

STRUCTURE: PRØPELLANT TANK STRUCTURE (ELEMENT 2)

PRØDUCTIØN RATE: 2 PER YEAR

VARIATIØN FRØM THE NØMINAL: NØNE

TØTAL PRØGRAM LENGTH: 5 YEARS

LABØR RATES-($/HR): PRE-MFG.- 15. ; Q.C.- 15. ; MFG.- 15.

TØØLING	UNIT CØST (K$)	NØ. UNITS	TØTAL CØST (K$)
100 PØWER SAW	8	1	8
101 WØRK PLATFØRM	2	1	2
102 SCRIBE ARM	1	1	1
120 LATHE FIXTURE # 1	12	1	12
121 LATHE FIXTURE # 2	12	1	12
122 LATHE FIXTURE # 3	12	1	12
130 SPINNING MILL-PØWER SHEAR-(NUM. CØNTR.)	3250	1	3250
140 HEAT TREAT ØVEN (25'X25'X40')	350	1	350
141 QUENCH TANK (25'X25'X40')	100	1	100
150 DØME RØTATING TØØL	125	1	125
151 ETCH CLEANING TANK (25'X25'X12')	50	1	50
152 ETCH CLEANING TANK (25'X25'X40')	100	1	100
160 JAMB RING WELDER STAND	30	1	30
161 JAMB CLAMPS	2	1	2
162 JAMB RING/DØLLAR ØPENING TRIMMER	5	1	5
163 JAMB RING/DØLLAR WELDER	7	1	7
164 X-RAY UNIT	18	1	18
170 SPRAY BØØTH	20	1	20
171 NEØPRENE MASKANT SPRAY	4	1	4
172 MASKANT CUT STENCIL # 1	1	4	4
173 MASKANT CUT STENCIL # 2	1	4	4
174 MASKANT CUT STENCIL # 3	1	4	4
175 MASKANT CUT STENCIL # 4	1	4	4
180 CHEM MILL (25'X25'X12')	75	1	75
190 ANØDIZE (25'X25'X40')	75	2	150
200 LØAD CELL # 1	2	1	2
201 HØIST SPREADER BAR #1	0.8	1	0.8
202 HØIST SPREADER BAR #2	0.8	1	0.8
203 HØIST SPREADER BAR #3	0.8	1	0.8
204 PICKUP PØSITIØNER	7	1	7
205 STUD WELDER HEAD	10	1	10
210 WELD GRINDER(PØRTABLE)	1	3	3
220 AMMØNIA GAS PRESSURE TEST RIG	10	1	10
230 X-RAY HØLDING FIXTURE	15	1	15
231 X-RAY UNIT	18	1	18
240 TRANSPØRT FIXTURE	4	2	8
250 DØME TØ RING WELD FIXTURE	12	1	12
251 WELDING HEAD	18	1	18
252 X-RAY UNIT	18	1	18
260 STRETCH PRESS	20	1	20
261 RING DIE #1	2	1	2
262 RING DIE #2	2	1	2
263 RING DIE #3	2	1	2
270 RING EXTRUSIØN CUTTER	0.5	1	0.5
271 RING WELD FIXTURE	20	1	20
272 RING WELD FIXTURE SET 1	1	1	1
273 RING WELD FIXTURE SET 2	1	1	1
274 WELDING HEAD	10	1	10
280 BØNDING GANTRY	40	1	40
281 HEAT/PRESSURE DØME	80	1	80
282 VACUUM BAG	8	1	8
283 BLEEDER CLØTH	2	1	2
284 VACUUM PUMP	2	1	2
285 SØNIC MEASURING DEVICE& AUTØ RDØUT	25	1	25
290 CØMMØN BULKH RING BUTT WLD FIXT	8	1	8
291 WELDING HEAD	18	1	18
300 CØM BULKH LATHE FIXTURE	12	1	12
301 RING CUTTING TØØL	1	1	1
310 SPREADER BARS(HØIST)	1	1	1
311 LØAD CELL	2	1	2
320 LØX TANK WELD FIXTURE	35	1	35
321 DRILL	1	1	1
322 DRILL JIG	2	1	2
323 WELDER	18	1	18
330 SKIN MILL(10'X40')	500	1	500
340 DRILL TEMPLATE	0.5	2	1
341 PØWER DRILL	1	2	2
350 BRAKE-40'	150	1	150
360 SEGMENT TRIM FIXTURE(SMALL)	35	1	35
361 PØWER CUTTER	5	1	5
370 SPREADER BARS	0.2	14	2.8
371 LØNGITUDINAL WELD FIXTURE	45	1	45
372 WELDER HEAD	18	1	18
380 END TRIM/RING WELD DØLLY	75	1	75
381 WELD FIXTURE	5	1	5
382 WELDER HEAD	18	1	18
410 X-RAY UNIT	18	1	18
420 HØIST SPREADER BAR	1.5	2	3
421 LØAD CELL	2	1	2
430 TANK ASSEM TØWER	200	1	200
431 HEAT BLANKET	12	1	12
432 WELDER HEAD	18	1	18
433 X-RAY UNIT	18	1	18
434 HØISTING YØKE & CRANE	50	1	50
440 HYDRØSTATIC TEST EQUIP	100	1	100
441 DEGREASER	80	1	80
450 TANK DØLLY	40	1	40
451 HØIST YØKE	10	1	10
452 LØAD CELL	2	1	2
TØTAL TØØLING CØST (K$)			6195.7

FACILITIES	TØTAL CØST (K$)
500 CØNSØLIDATED MANUFACTURING & ASSEMBLY PLANT	6972

NEAR-TERM PRE-MANUFACTURING ØPERATIØNS

NØN-RECURRING CØSTS

ITEM	M/HRS	TØTAL CØST (K$)
800 REVIEW PRØGRAM DIRECTIVES	700.	10.5
810 MFG. PRELIMINARY SCHEDULES	700.	10.5
820 PRØDUCIBILITY STUDIES	9380.	140.7
830 IDENTIFY/ØRDER LØNG LEAD ITEMS	1890.	28.35
840 ACCUMULATE/REVIEW ENGR & QC DØCUMENT.	1890.	28.35
850 DEVELØP SUB-ASSEMBLY & PARTS SCHEDULE	9380.	140.7
860 MFG. PLANNING ØPERATIØNS	14000.	210
870 DESIGN/PRØCURE TØØLING	22400.	336
880 VENDØR EVALUATIØN & SELECTIØN	4200.	63
NØN-RECURRING TØTALS	64540.	968.1

RECURRING CØSTS

ITEM	M/HRS	TØTAL CØST (K$)
900 EXPEDITE IN-HØUSE/PURCHASE PARTS	8000.	120
910 REVIEW PRØGRESS WITH PRØGRAM ØFFICE	2000.	30
RECURRING TØTALS	10000	150

TØTAL RECURRING AND NØN-RECURRING PRE-MFG. CØSTS= 1118.1

MANUFACTURING PRØCESSES	MAT'L CØST (K$)	Q.C. LABØR (M/HR)	MFG. LABØR (M/HR)	TØTAL CØST (K$)
1000 TANK ASSEMBLY				
1001 INSPECT FWD DØME	0	200	100	4.5
1002 INSPECT LØX TANK	0	400	100	7.5
1003 MØVE F/D+L/T TØ ASSY TØWER	0	0	200	3
1004 WELD CYL TØ L/T(INTER)+INSP	3.1	620	1220	30.7
1005 WELD CYL TØ L/T(EXTER)+INSP	3.1	270	270	11.2
1006 WELD CYL TØ F/D(INTER)+INSP	3.1	620	920	26.2
1007 WELD CYL TØ F/D(EXTER)+INSP	3.1	520	520	18.7
1008 HYDRØSTATIC TEST	0	2000	4000	90
1009 DEGREASE	0	500	1000	22.5
1010 WEIGH+STØRE	0	200	1250	21.75
1020 LØX TANK ASSEMBLY				
1021 MATE C/B+A/D:SEAL WELD+INSP	13.4	1400	1520	57.2
1022 X-RAY ALL WELDS+WEIGH	1.4	100	200	5.9
1023 MØVE TØ A/A	0	50	100	2.25
1030 AFT DØME ASSY				
1031 VERIFY MTL FØR A/D	26	0	0	26
1032 SCRIBE+SAW BLK TØ REQ SHAPE	0	160	320	7.2
1033 SHEAR SPIN FØRM+INSP	0	200	460	9.9
1034 CLEAN+ANNEAL+QUENCH+INSP	0	240	320	8.4
1035 SPIN FØRM TØ SHAPE+INSP	0	300	600	13.5
1036 CLEAN+ANNEAL+QUENCH+INSP	0	240	320	8.4
1037 FINAL FØRMSPIN+STA TRIM+INSP	0	300	600	13.5
1038 CUT+TRIM C/C ØPNG+DEBURR+INSP	0	80	260	5.1
1039 CLN+HEAT TREAT+AGE+INSP+STØRE	0	300	540	12.6
1040 MASK+CHEM MILL+DEBURR+INSP	78	900	0	91.5
1041 CLEAN+ANØDIZE+INSP	0	180	270	6.75
1042 WEIGH+STØRE	0	50	90	2.1
1043 WELD JAMB+INSP	2.5	100	150	6.25
1044 WELD STUDS+FITTINGS+INSP	1.1	100	150	4.85
1045 GRIND ALL WELDS+DYE-PEN INSP	0	600	2000	39
1046 PERFØRM LEAK CHECK	1	100	300	7
1047 X-RAY ALL DØME WELDS+WEIGH	1.5	500	30	9.45
1048 TRANSPØRT TØ L/T A/A	0	50	100	2.25
1050 CØMMØN BULKHEAD ASSY				
1051 ETCH CLEAN AFT DØME	2	150	300	8.75
1052 ETCH CLEAN FWD DØME	2	150	300	8.75
1053 FIT+BØND HØNEYCØMB+INSP	38	4000	16000	338
1054 BUTT WELD Y RINGS+LK CK+INSP	4	110	280	9.85
1055 MACHINE RING BUTT WELDS	0	200	800	15
1056 X-RAY WELD+U/T DØME+WGH+STØRE	41.7	300	100	47.7
1060 CØMMØN BULKHEAD F/D				
1061 VERIFY MTL FØR C/B F/D	8	0	0	8
1062 SCRIBE+SAW BLK TØ REQ SHAPE	0	160	320	7.2
1063 SHEAR SPIN FØRM+INSP	0	200	460	9.9
1064 CLEAN+ANNEAL+QUENCH+INSP	0	240	320	8.4
1065 SPIN FØRM TØ SHAPE+INSP	0	300	600	13.5
1066 CLEAN+ANNEAL+QUENCH+INSP	0	240	320	8.4
1067 [illegible] FØRM SPIN+STA TRIM+INSP	0	300	600	13.5
1068 CUT+TRIM C/C ØPNG+DEBURR+INSP	0	80	260	5.1
1069 CLN+HEAT TREAT+AGE+INSP+STØRE	0	300	540	12.6
1070 MASK+CHEM MILL+DEBURR+INSP	38	900	0	51.5
1071 CLEAN+ANØDIZE+INSPECT	0	270	360	9.45
1072 WELD DØME TØ RING+INSP	3.2	180	300	10.4
1073 WELD CENTER CAP TØ DØME+INSP	1.4	100	180	5.6
1074 GRIND ALL WELDS+DYE-PEN INSP	0	600	2000	39
1075 X-RAY ALL WELDS	2.3	0	0	2.3
1076 PERFØRM LEAK CHECK+WGH+STØRE	1	150	400	9.25
1080 RING:F/D:CØMMØN BULKHEAD				
1081 VERIFY MTL FØR 1 F/D Y RING	3.5	0	0	3.5
1082 FØRM+INSP	0	140	260	6
1083 TRIM+CLEAN+AGE+INSP	0	40	140	2.7
1084 ANØDIZE+WEIGH+STØRE	0	40	80	1.8
1085 WELD SEG+STRAIGHTEN RING+INSP	0	200	400	9
1086 MILL RING FACE+INSP+STØRE	0	250	500	11.25
1090 CØMMØN BULKHEAD AFT DØME				
1091 VERIFY MTL FØR C/B AFT DØME	9	0	0	9
1092 SCRIBE+SAW BLK TØ REQ SHAPE	0	160	320	7.2
1093 SHEAR SPIN FØRM+INSP	0	200	460	9.9
1094 CLEAN+ANNEAL+QUENCH+INSP	0	240	320	8.4
1095 SPIN FØRM TØ SHAPE+INSP	0	300	600	13.5
1096 CLEAN+ANNEAL+QUENCH+INSP	0	240	320	8.4
1097 FINAL FØRM SPIN+STA TRIM+INSP	0	300	600	13.5
1098 CUT+TRIM C/C ØPNG+DEBURR+INSP	0	80	260	5.1
1099 CLN+HEAT TREAT+AGE+INSP+STØRE	0	300	540	12.6
1100 MASK+CHEM MILL+DEBURR+INSP	32	900	0	45.5
1110 CLEAN+ANØDIZE+INSP	0	270	360	9.45
1111 WELD DØME TØ RING+INSP	3.2	180	300	10.4
1112 WELD CENTER CAP TØ DØME+INSP	2.8	100	180	7
1113 GRIND ALL WELDS+DYE-PEN INSP	0	600	2000	39
1114 X-RAY ALL WELDS	2.3	0	0	2.3
1115 PERFØRM LEAK CHECK+WGH+STØRE	1	150	400	9.25
2010 RING:A/D:CØMMØN BULKHEAD				
2011 VERIFY MTL FØR 1 A/D Y RING.	3.5	0	0	3.5
2012 FØRM+INSP	0	140	260	6
2013 TRIM+CLEAN+AGE+INSP	0	40	140	2.7
2014 ANØDIZE+WEIGH+STØRE	0	40	80	1.8
2015 WELD SEG+STRAIGHTEN RING+INSP	0	200	400	9
2016 MILL RING FACE+INSP+STØRE	0	250	500	11.25
2020 TANK CYLINDER				
2021 VERIFY MTL FØR 7 TANK SEG(S)	310	0	0	310
2022 MILL EDGES	65	280	560	77.6
2023 MILL WAFFLE PATTERN	325	280	560	337.6
2024 ULTRASØNIC INSP	138.5	0	0	138.5
2025 MØVE SEG(S) TØ A/A	0	70	140	3.15
2027 DRILL SPREADER BAR HØLES	0	140	280	6.3
2029 HEAT TREAT(ANNEAL)	0	0	140	2.1
2030 FØRM 7 SKINS+CLN+AGE+INSP	0	980	2030	45.15
2031 ANØDIZE+TRIM+WGH+INSTL S/B(S)	0	310	450	11.4
2041 WELD SEG(S)+INSP	11	800	1600	47
2043 TRIM CYL+WELD RINGS	6.2	340	660	21.2
2044 X-RAY ALL WELDS+WEIGH+STØRE	13	100	400	20.5
2050 RING TANK CYL				
2051 VERIFY MTL FØR 2 RINGS(CYL)	7.	0	0	7
2052 FØRM 8 SEG(S)+INSP	0	280	520	12
2053 TRIM+AGE+INSP	0	80	280	5.4
2054 ANØDIZE+WEIGH+STØRE	0	80	160	3.6
2055 WELD SEG+STRTN RINGS+INSP	0	400	800	18
2056 MILL RING FACE+INSP+WEIGH	0	450	900	20.25
2057 MØVE RINGS TØ A/A	0	50	100	2.25
2060 FWD DØME				
2061 VERIFY MTL FØR FWD DØME	13	0	0	13
2062 SCRIBE+SAW BLK TØ REQ SHAPE	0	160	320	7.2
2063 SHEAR SPIN FØRM+INSP	0	200	460	9.9
2064 CLEAN+ANNEAL+QUENCH+INSP	0	240	320	8.4
2065 SPIN FØRM TØ SHAPE+INSP	0	300	600	13.5
2066 CLEAN+ANNEAL+QUENCH+INSP	0	240	320	8.4
2067 FINAL FØRM SPIN+STA TRIM+INSP	0	300	600	13.5
2068 CUT+TRIM C/C ØPNG+DEBURR+INSP	0	80	260	5.1
2069 CLN+HEAT TREAT+AGE+INSP+STØRE	0	300	540	12.6
2070 MASK+CHEM MILL+DEBURR+INSP	78	900	0	91.5
2071 CLEAN+ANØDIZE+INSP	0	180	270	6.75
2072 WEIGH+STØRE	0	50	90	2.1
2073 WELD JAMB+INSP	2.5	100	150	6.25
2074 WELD STUDS+FITTINGS+INSP	1.1	100	150	4.85
2075 GRIND ALL WELDS+ [illegible] -PEN INSP	0	600	2000	39
2076 PERFØRM LEAK CHECK	1	100	300	7
2077 X-RAY ALL WELDS+WEIGH	1.5	500	30	9.45
2078 LD ØN TRNSPR+MØVE F/D TØ A/A	0	60	120	2.7
	1309.	34620	67880	2846.5
LABØR CØST (K$)		(519.3)	(1018.2)	

SUMMARY ØF RESULTS

	MAT'L CØST (K$)	Q.C. LABØR (M/HR)	MFG. LABØR (M/HR)	PRE-MFG. LABØR (M/HR)	TØTAL CØST (K$)
TØØLING					6195.7
FACILITIES					6972
PRE-MANUFACTURING					
NØN-RECURRING CØST				64540.	968.1
RECURRING CØST				10000	150
MFG. PRØCESSES	1309.	34620	67880		2846.5
	1309.	34620	67880	74540.	17132.3
LABØR IN (K$)		(519.3)	(1018.2)		

Table 5-25

Manufacturing Cost Analysis

MANUFACTURING COST ANALYSIS
****
09/23/76

LINE: ADVANCED MANUFACTURING LINE (LINE 3)

STRUCTURE: PROPELLANT TANK STRUCTURE (ELEMENT 2)

PRODUCTION RATE: 20 PER YEAR

VARIATION FROM THE NOMINAL: NONE

TOTAL PROGRAM LENGTH: 5 YEARS

LABOR RATES-($/HR): PRE-MFG.- 15. ; Q.C.- 15. ; MFG.- 15.

TOOLING	UNIT COST (K$)	NO. UNITS	TOTAL COST (K$)
100 POWER SAW	8	3	24
101 WORK PLATFORM	2	3	6
102 SCRIBE ARM	1	3	3
120 LATHE FIXTURE # 1	12	1	12
121 LATHE FIXTURE # 2	12	1	12
122 LATHE FIXTURE # 3	12	1	12
130 SPINNING MILL-POWER SHEAR-(NUM. CONTR.)	3250	1	3250
140 HEAT TREAT OVEN (25'X25'X40')	350	2	700
141 QUENCH TANK (25'X25'X40')	100	1	100
150 DOME ROTATING TOOL	125	1	125
151 ETCH CLEANING TANK (25'X25'X12')	50	1	50
152 ETCH CLEANING TANK (25'X25'X40')	100	1	100
160 JAMB RING WELDER STAND	30	2	60
161 JAMB CLAMPS	2	2	4
162 JAMB RING/DOLLAR OPENING TRIMMER	5	2	10
163 JAMB RING/DOLLAR WELDER	7	2	14
164 X-RAY UNIT	18	2	36
170 SPRAY BOOTH	20	1	20
171 NEOPRENE MASKANT SPRAY	4	1	4
172 MASKANT CUT STENCIL # 1	1	8	8
173 MASKANT CUT STENCIL # 2	1	8	8
174 MASKANT CUT STENCIL # 3	1	8	8
175 MASKANT CUT STENCIL # 4	1	8	8
180 CHEM MILL (25'X25'X12')	75	2	150
190 ANODIZE (25'X25'X40')	75	4	300
200 LOAD CELL # 1	2	1	2
201 HOIST SPREADER BAR #1	0.8	1	0.8
202 HOIST SPREADER BAR #2	0.8	1	0.8
203 HOIST SPREADER BAR #3	0.8	1	0.8
204 PICKUP POSITIONER	7	2	14
205 STUD WELDER HEAD	10	2	20
210 WELD GRINDER(PORTABLE)	1	6	6
220 AMMONIA GAS PRESSURE TEST RIG	10	4	40
230 X-RAY HOLDING FIXTURE	15	4	60
231 X-RAY UNIT	18	4	72
240 TRANSPORT FIXTURE	4	6	24
250 DOME TO RING WELD FIXTURE	12	1	12
251 WELDING HEAD	18	1	18
252 X-RAY UNIT	18	1	18
260 STRETCH PRESS	20	1	20
261 RING DIE #1	2	1	2
262 RING DIE #2	2	1	2
263 RING DIE #3	2	1	2
270 RING EXTRUSION CUTTER	0.5	1	0.5
271 RING WELD FIXTURE	20	1	20
272 RING WELD FIXTURE SET 1	1	1	1
273 RING WELD FIXTURE SET 2	1	1	1
274 WELDING HEAD	10	1	10
280 BONDING GANTRY	40	4	160
281 HEAT/PRESSURE DOME	80	4	320
282 VACUUM BAG	8	4	32
283 BLEEDER CLOTH	2	4	8
284 VACUUM PUMP	2	4	8
285 SONIC MEASURING DEVICE& AUTO RDOUT	25	4	100
290 COMMON BULKH RING BUTT WLD FIXT	8	2	16
291 WELDING HEAD	18	2	36
300 COM BULKH LATHE FIXTURE	12	1	12
301 RING CUTTING TOOL	1	1	1
310 SPREADER BARS(HOIST)	1	2	2
311 LOAD CELL	2	2	4
320 LOX TANK WELD FIXTURE	35	3	105
321 DRILL	1	3	3
322 DRILL JIG	2	3	6
323 WELDER	18	3	54
331 SKIN MILL(18'X40')	1000	1	1000
340 DRILL TEMPLATE	0.5	4	2
341 POWER DRILL	1	4	4
350 BRAKE-40'	150	1	150
361 POWER CUTTER	5	2	10
362 SEGMENT TRIM FIXTURE(LARGE)	60	2	120
370 SPREADER BARS	0.2	28	5.6
371 LONGITUDINAL WELD FIXTURE	45	2	90
372 WELDER HEAD	18	2	36
380 END TRIM/RING WELD DOLLY	75	2	150
381 WELD FIXTURE	5	2	10
382 WELDER HEAD	18	2	36
410 X-RAY UNIT	18	1	18
420 HOIST SPREADER BAR	1.5	4	6
421 LOAD CELL	2	2	4
430 TANK ASSEM TOWER	200	6	1200
431 HEAT BLANKET	12	6	72
432 WELDER HEAD	18	6	108
433 X-RAY UNIT	18	6	108
434 HOISTING YOKE & CRANE	50	6	300
440 HYDROSTATIC TEST EQUIP	100	6	600
441 DEGREASER	80	6	480
450 TANK DOLLY	40	6	240
451 HOIST YOKE	10	6	60
452 LOAD CELL	2	6	12
TOTAL TOOLING COST (K$)			11059.5

FACILITIES	TOTAL COST (K$)
500 CONSOLIDATED MANUFACTURING & ASSEMBLY PLANT	16680

NEAR-TERM PRE-MANUFACTURING OPERATIONS

NON-RECURRING COSTS

ITEM	M/HRS	TOTAL COST (K$)
800 REVIEW PROGRAM DIRECTIVES	700.	10.5
810 MFG. PRELIMINARY SCHEDULES	700.	10.5
820 PRODUCIBILITY STUDIES	9380.	140.7
830 IDENTIFY/ORDER LONG LEAD ITEMS	1890.	28.35
840 ACCUMULATE/REVIEW ENGR & QC DOCUMENT.	1890.	28.35
850 DEVELOP SUB-ASSEMBLY & PARTS SCHEDULE	9380.	140.7
860 MFG. PLANNING OPERATIONS	14000.	210
870 DESIGN/PROCURE TOOLING	22400.	336
880 VENDOR EVALUATION & SELECTION	4200.	63
NON-RECURRING TOTALS	64540.	968.1

RECURRING COSTS

ITEM	M/HRS	TOTAL COST (K$)
900 EXPEDITE IN-HOUSE/PURCHASE PARTS	80000.	1200
910 REVIEW PROGRESS WITH PROGRAM OFFICE	20000.	300
RECURRING TOTALS	100000	1500

TOTAL RECURRING AND NON-RECURRING PRE-MFG. COSTS= 2468.1

MANUFACTURING PROCESSES	MAT'L COST (K$)	Q.C. LABOR (M/HR)	MFG. LABOR (M/HR)	TOTAL COST (K$)
1000 TANK ASSEMBLY				
1001 INSPECT FWD DOME	0	2000	1000	45
1002 INSPECT LOX TANK	0	4000	1000	75
1003 MOVE F/D+L/T TO ASSY TOWER	0	0	2000	30
1004 WELD CYL TO L/T(INTER)+INSP	31.	6200	12200	307
1005 WELD CYL TO L/T(EXTER)+INSP	31.	2700	2700	112
1006 WELD CYL TO F/D(INTER)+INSP	31.	6200	9200	262
1007 WELD CYL TO F/D(EXTER)+INSP	31.	5200	5200	187
1008 HYDROSTATIC TEST	0	20000	40000	900
1009 DEGREASE	0	5000	10000	225
1010 WEIGH+STORE	0	2000	12500	217.5
1020 LOX TANK ASSEMBLY				
1021 MATE C/B+A/D:SEAL WELD+INSP	134.	14000	15200	572
1022 X-RAY ALL WELDS+WEIGH	14.	1000	2000	59
1023 MOVE TO A/A	0	500	1000	22.5
1030 AFT DOME ASSY				
1031 VERIFY MTL FOR A/D	260	0	0	260
1032 SCRIBE+SAW BLK TO REQ SHAPE	0	1600	3200	72
1033 SHEAR SPIN FORM+INSP	0	2000	4600	99
1034 CLEAN+ANNEAL+QUENCH+INSP	0	2400	3200	84
1035 SPIN FORM TO SHAPE+INSP	0	3000	6000	135
1036 CLEAN+ANNEAL+QUENCH+INSP	0	2400	3200	84
1037 FINAL FORMSPIN+STA TRIM+INSP	0	3000	6000	135
1038 CUT+TRIM C/C OPNG+DEBURR+INSP	0	800	2600	51
1039 CLN+HEAT TREAT+AGE+INSP+STORE	0	3000	5400	126
1040 MASK+CHEM MILL+DEBURR+INSP	780.	9000	0	915
1041 CLEAN+ANODIZE+INSP	0	1800	2700	67.5
1042 WEIGH+STORE	0	500	900	21
1043 WELD JAMB+INSP	25	1000	1500	62.5
1044 WELD STUDS+FITTINGS+INSP	11	1000	1500	48.5
1045 GRIND ALL WELDS+DYE-PEN INSP	0	6000	20000	390
1046 PERFORM LEAK CHECK	10	1000	3000	70
1047 X-RAY ALL DOME WELDS+WEIGH	15.	5000	300	94.5
1048 TRANSPORT TO L/T A/A	0	500	1000	22.5
1050 COMMON BULKHEAD ASSY				
1051 ETCH CLEAN AFT DOME	20	1500	3000	87.5
1052 ETCH CLEAN FWD DOME	20	1500	3000	87.5
1053 FIT+BOND HONEYCOMB+INSP	380	40000	160000	3380
1054 BUTT WELD Y RINGS+LK CK+INSP	40	1100	2800	98.5
1055 MACHINE RING BUTT WELDS	0	2000	8000	150
1056 X-RAY WELD+U/I DOME+WGH+STORE	417.	3000	1000	477
1060 COMMON BULKHEAD F/D				
1061 VERIFY MTL FOR C/B F/D	80	0	0	80
1062 SCRIBE+SAW BLK TO REQ SHAPE	0	1600	3200	72
1063 SHEAR SPIN FORM+INSP	0	2000	4600	99
1064 CLEAN+ANNEAL+QUENCH+INSP	0	2400	3200	84
1065 SPIN FORM TO SHAPE+INSP	0	3000	6000	135
1066 CLEAN+ANNEAL+QUENCH+INSP	0	2400	3200	84
1067 FINAL FORM SPIN+STA TRIM+INSP	0	3000	6000	135
1068 CUT+TRIM C/C OPNG+DEBURR+INSP	0	800	2600	51
1069 CLN+HEAT TREAT+AGE+INSP+STORE	0	3000	5400	126
1070 MASK+CHEM MILL+DEBURR+INSP	380	9000	0	515
1071 CLEAN+ANODIZE+INSPECT	0	2700	3600	94.5
1072 WELD DOME TO RING+INSP	32.	1800	3000	104
1073 WELD CENTER CAP TO DOME+INSP	14.	1000	1800	56
1074 GRIND ALL WELDS+DYE-PEN INSP	0	6000	20000	390
1075 X-RAY ALL WELDS	23.	0	0	23
1076 PERFORM LEAK CHECK+WGH+STORE	10	1500	4000	92.5
1080 RING:F/D:COMMON BULKHEAD				
1081 VERIFY MTL FOR 1 F/D Y RING	35	0	0	35
1082 FORM+INSP	0	1400	2600	60
1083 TRIM+CLEAN+AGE+INSP	0	400	1400	27
1084 ANODIZE+WEIGH+STORE	0	400	800	18
1085 WELD SEG+STRAIGHTEN RING+INSP	0	2000	4000	90
1086 MILL RING FACE+INSP+STORE	0	2500	5000	112.5
1090 COMMON BULKHEAD AFT DOME				
1091 VERIFY MTL FOR C/B AFT DOME	90	0	0	90
1092 SCRIBE+SAW BLK TO REQ SHAPE	0	1600	3200	72
1093 SHEAR SPIN FORM+INSP	0	2000	4600	99
1094 CLEAN+ANNEAL+QUENCH+INSP	0	2400	3200	84
1095 SPIN FORM TO SHAPE+INSP	0	3000	6000	135
1096 CHEAN+ANNEAL+QUENCH+INSP	0	2400	3200	84
1097 FINAL FORM SPIN+STA TRIM+INSP	0	3000	6000	135
1098 CUT+TRIM C/C OPNG+DEBURR+INSP	0	800	2600	51
1099 CLN+HEAT TREAT+AGE+INSP+STORE	0	3000	5400	126
1100 MASK+CHEM MILL+DEBURR+INSP	320	9000	0	455
1110 CLEAN+ANODIZE+INSP	0	2700	3600	94.5
1111 WELD DOME TO RING+INSP	32.	1800	3000	104
1112 WELD CENTER CAP TO DOME+INSP	28.	1000	1800	70
1113 GRIND ALL WELDS+DYE-PEN INSP	0	6000	20000	390
1114 X-RAY ALL WELDS	23.	0	0	23
1115 PERFORM LEAK CHECK+WGH+STORE	10	1500	4000	92.5
2010 RING:A/D:COMMON BULKHEAD				
2011 VERIFY MTL FOR 1 A/D Y RING	35	0	0	35
2012 FORM+INSP	0	1400	2600	60
2013 TRIM+CLEAN+AGE+INSP	0	400	1400	27
2014 ANODIZE+WEIGH+STORE	0	400	800	18
2015 WELD SEG+STRAIGHTEN RING+INSP	0	2000	4000	90
2016 MILL RING FACE+INSP+STORE	0	2500	5000	112.5
2020 TANK CYLINDER				
2021 VERIFY MTL FOR 4 TANK SEG(S)	3100	0	0	[illegible]
2022 MILL EDGES	620	1000	2000	[illegible]
2023 MILL WAFFLE PATTERN	3100	2000	4000	3190
2024 ULTRASONIC INSP	1385.	0	0	1385
2025 MOVE SEG(S) TO A/A	0	0	0	0
2027 DRILL SPREADER BAR HOLES	0	1000	2000	[illegible]
2029 HEAT TREAT(ANNEAL)	0	0	1400	21
2030 FORM 4 SKINS+CLN+AGE+INSP	0	7800	16000	357
2031 ANODIZE+TRIM+WGH+INSTL S/B(S)	0	3100	4500	114
2041 WELD SEG(S)+INSP	63.	6000	11000	318
2043 TRIM CYL+WELD RINGS	62.	3400	6600	212
2044 X-RAY ALL WELDS+WEIGH+STORE	130	1000	4000	205
2050 RING TANK CYL				
2051 VERIFY MTL FOR 2 RINGS(CYL)	70	0	0	70
2052 FORM 8 SEG(S)+INSP	0	2800	5200	120
2053 TRIM+AGE+INSP	0	800	2800	54
2054 ANODIZE+WEIGH+STORE	0	800	1600	36
2055 WELD SEG+STRTN RINGS+INSP	0	4000	8000	180
2056 MILL RING FACE+INSP+WEIGH	0	4500	9000	202.5
2057 MOVE RINGS TO A/A	0	500	1000	22.5
2060 FWD DOME				
2061 VERIFY MTL FOR FWD DOME	130	0	0	130
2062 SCRIBE+SAW BLK TO REQ SHAPE	0	1600	3200	72
2063 SHEAR SPIN FORM+INSP	0	2000	4600	99
2064 CLEAN+ANNEAL+QUENCH+INSP	0	2400	3200	84
2065 SPIN FORM TO SHAPE+INSP	0	3000	6000	135
2066 CLEAN+ANNEAL+QUENCH+INSP	0	2400	3200	84
2067 FINAL FORM SPIN+STA TRIM+INSP	0	3000	6000	135
2068 CUT+TRIM C/C OPNG+DEBURR+INSP	0	800	2600	51
2069 CLN+HEAT TREAT+AGE+INSP+STORE	0	3000	5400	126
2070 MASK+CHEM MILL+DEBURR+INSP	780.	9000	0	915
2071 CLEAN+ANODIZE+INSP	0	1800	2700	67.5
2072 WEIGH+STORE	0	500	900	21
2073 WELD JAMB+INSP	25	1000	1500	62.5
2074 WELD STUDS+FITTINGS+INSP	11	1000	1500	48.5
2075 GRIND ALL WELDS+DYE-PEN INSP	0	6000	20000	390
2076 PERFORM LEAK CHECK	10	1000	3000	70
2077 X-RAY ALL WELDS+WEIGH	15.	5000	300	94.5
2078 LD ON TRNSPR+MOVE F/D TO A/A	0	600	1200	27
	12863	338500	662100	27872
LABOR COST (K$)		(5077.5)	(9931.5)	

SUMMARY OF RESULTS

	MAT'L COST (K$)	Q.C. LABOR (M/HR)	MFG. LABOR (M/HR)	PRE-MFG. LABOR (M/HR)	TOTAL COST (K$)
TOOLING					11059.5
FACILITIES					16680
PRE-MANUFACTURING					
NON-RECURRING COST				64540.	968.1
RECURRING COST				100000	1500
MFG. PROCESSES	12863	338500	662100		27872
	12863	338500	662100	164540.	58079.6
LABOR IN (K$)		(5077.5)	(9931.5)		

5.4.2.2 Manufacturing Processes and Tooling

Eliminating the need for much conventional equipment and tooling, the advanced manufacturing Line 3 will implement a numerically controlled machining center. This will permit the replacement of skins and rings with a single forging and thereby eliminate the joining operation. The spot-welding of longerons is retained as a compromise with design in order to save raw material and to reduce machining time. However, the machining of integral longitudinal stiffeners is considered within the range of accomplishment for Line 3.

Within the decade allowed for the development of Line 3 concepts, there should be significant improvements in plastics technology. Reflecting this, the honeycomb bulkhead will be planned with ambient-temperature cured adhesive systems. This will eliminate the space furnaces or autoclaves necessary for heat curing and also will simplify tooling.

5.4.2.3 Cost Considerations

Although the numerically controlled machining center will be much more expensive than the machines it replaces, it is capable of a greater work output with fewer and simpler work-holding fixtures required. The single machine also will save floor space and eliminate material handling and scheduling problems.

5.4.2.4 Summary

The summary of costs and tooling requirements for operation of Line 3 is given in Tables 5-26 and 5-27.

Table 5-26

Manufacturing Cost Analysis, 2 Per Year, Line 3, Element 1

MANUFACTURING COST ANALYSIS

09/28/70

LINE: ADVANCED MANUFACTURING LINE (LINE 3)

STRUCTURE: SUPPORT FRUSTUM STRUCTURE (ELEMENT 1)

PRODUCTION RATE: 2 PER YEAR

VARIATION FROM THE NOMINAL: NONE

TOTAL PROGRAM LENGTH: 5 YEARS

LABOR RATES-($/HR): PRE-MFG.- 15. ; G.C.- 15. ; MFG.- 15.

TOOLING	UNIT COST (K$)	NO. UNITS	TOTAL COST (K$)
50 CONTROL MASTER FIXTURE	5	2	10
60 MASTER DRILL FIXTURE	5	2	10
70 DRILL FIXTURES	5	2	10
80 INSERT LOCATING FIXTURES	2	2	4
90 BULKHEAD ASSEMBLY FIXTURES	3	2	6
100 CHEM CLEANING TANKS	15	1	15
110 SPOT WELDER	20	1	20
112 WELD ELECTRODE	0.075	1	0.075
120 TESTING MACHINE	24	1	24
122 TEST FIXTURE	0.075	1	0.075
130 WELD ASSEMBLY FIXTURE	1	1	1
140 TORQUE TOOLS & WRENCH SET	0.15	1	0.15
150 INSPECTION STATION	0.5	1	0.5
160 IRON WORKER (BUFFALO)	6	1	6
162 NOTCH & SHEAR DIE	0.3	1	0.3
170 DEGREASER	2.5	1	2.5
180 N/C BORING MILL	250	1	250
190 HOLDING FIXTURE	1.4	2	2.8
200 CUTTING TOOLS	0.1	1	0.1
210 INSPECTION STATION	3	1	3
212 INSPECTION INSTRUMENTS	0.5	1	0.5
220 CLEAN & ALODINE TANKS	15	1	15
230 WEIGH SCALE	0.5	1	0.5
TOTAL TOOLING COST (K$)			381.5

MANUFACTURING PROCESSES	MAT'L COST (K$)	G.C. LABOR (M/HR)	MFG. LABOR (M/HR)	TOTAL COST (K$)
1000 FRUSTUM ASSEMBLY				
1002 VERIFY MAT'L,CLEAN,BAG PARTS	0.1	5	40	0.775
1004 MAKE SPOT WELD SPEC.,INSP	0.1	30	10	0.7
1006 LOAD PARTS IN FIXTURE,WELD,INSP	0	30	60	1.35
1008 BOLT ASSEMBLE BULKHEAD	50	0	20	50.3
1009 CLEAN,IDENTIFY,INSPECT	0	20	20	0.6
1010 LONGERON				
1012 VERIFY MATERIAL	0.16	16	0	0.4
1014 NOTCH, SHEAR	0	0	16	0.24
1016 DEBURR,CLEAN, ALODINE	0	0	32	0.48
1017 IDENTIFY & INSPECT	0	16	0	0.24
1020 SHELL				
1022 VERIFY MATERIAL	4.5	30	0	4.95
1024 ROUGH FACE, TURN,BORE	0	0	60	0.9
1026 AGE, INSPECT	0	5	0	0.075
1028 ROUGH FACE, TURN, BORE	0	0	60	0.9
1030 AGE, INSPECT	0	5	0	0.075
1032 FINISH FACE, TURN,BORE	0	0	100	1.5
1034 DEBURR,CLEAN,ALODINE	0.25	0	40	0.85
1036 WEIGH, IDENTIFY, INSPECT	0	20	10	0.45
	55.11	177	468	64.785
LABOR COST (K$)		(2.655)	(7.02)	

FACILITIES	TOTAL COST (K$)
500 CONSOLIDATED MANUFACTURING & ASSEMBLY PLANT	620

NEAR-TERM PRE-MANUFACTURING OPERATIONS

NON-RECURRING COSTS

ITEM	M/HRS	TOTAL COST (K$)
800 REVIEW PROGRAM DIRECTIVES	700.	10.5
810 MFG. PRELIMINARY SCHEDULES	420.	6.3
820 PRODUCIBILITY STUDIES	700.	10.5
830 IDENTIFY/ORDER LONG LEAD ITEMS	500.	7.5
840 ACCUMULATE/REVIEW ENGR & QC DOCUMENT.	1120.	16.8
850 DEVELOP SUB-ASSEMBLY & PARTS SCHEDULE	528.	7.92
860 MFG. PLANNING OPERATIONS	3200.	48
870 DESIGN/PROCURE TOOLING	1400.	21
880 VENDOR EVALUATION & SELECTION	1120.	16.8
NON-RECURRING TOTALS	9688	145.32

RECURRING COSTS

ITEM	M/HRS	TOTAL COST (K$)
900 EXPEDITE IN-HOUSE/PURCHASE PARTS	2750.	41.25
910 REVIEW PROGRESS WITH PROGRAM OFFICE	550.	8.25
RECURRING TOTALS	3300	49.5

TOTAL RECURRING AND NON-RECURRING PRE-MFG. COSTS= 194.82

SUMMARY OF RESULTS

	MAT'L COST (K$)	Q.C. LABOR (M/HR)	MFG. LABOR (M/HR)	PRE-MFG. LABOR (M/HR)	TOTAL COST (K$)
TOOLING					381.5
FACILITIES					620
PRE-MANUFACTURING					
NON-RECURRING COST				9688	145.32
RECURRING COST				3300	49.5
MFG. PROCESSES	55.11	177	468		64.785
	55.11	177	468	12988	1261.1
LABOR IN (K$)		(2.655)	(7.02)		

Table 5-27

Manufacturing Cost Analysis, 20 Per Year, Line 3, Element 1

MANUFACTURING COST ANALYSIS
09/25/70

LINE: ADVANCED MANUFACTURING LINE (LINE 3)

STRUCTURE: SUPPORT FRUSTUM STRUCTURE (ELEMENT 1)

PRODUCTION RATE: 20 PER YEAR

VARIATION FROM THE NOMINAL: NONE

TOTAL PROGRAM LENGTH: 5 YEARS

LABOR RATES-($/HR): PRE-MFG.- 15. ; Q.C.- 15. ; MFG.- 15.

TOOLING

TOOLING	UNIT COST (K$)	NO. UNITS	TOTAL COST (K$)
50 CONTROL MASTER FIXTURE	5	2	10
60 MASTER DRILL FIXTURE	5	2	10
70 DRILL FIXTURES	5	2	10
80 INSERT LOCATING FIXTURES	2	2	4
90 BULKHEAD ASSEMBLY FIXTURES	3	2	6
100 CHEM CLEANING TANKS	15	1	15
110 SPOT WELDER	20	1	20
112 WELD ELECTRODE	0.075	1	0.075
120 TESTING MACHINE	24	1	24
122 TEST FIXTURE	0.075	1	0.075
130 WELD ASSEMBLY FIXTURE	1	1	1
140 TORQUE TOOLS & WRENCH SET	0.15	1	0.15
150 INSPECTION STATION	0.5	1	0.5
160 IRON WORKER (BUFFALO)	6	1	6
162 NOTCH & SHEAR DIE	0.3	1	0.3
170 DEGREASER	2.5	1	2.5
180 N/C BORING MILL	250	1	250
190 HOLDING FIXTURE	1.4	2	2.8
200 CUTTING TOOLS	0.1	1	0.1
210 INSPECTION STATION	3	1	3
212 INSPECTION INSTRUMENTS	0.5	1	0.5
220 CLEAN & ALODINE TANKS	15	1	15
230 WEIGH SCALE	0.5	1	0.5
TOTAL TOOLING COST (K$)			381.5

MANUFACTURING PROCESSES

MANUFACTURING PROCESSES	MAT'L COST (K$)	Q.C. LABOR (M/HR)	MFG. LABOR (M/HR)	TOTAL COST (K$)
1000 FRUSTUM ASSEMBLY				
1002 VERIFY MAT'L,CLEAN,BAG PARTS	1.	50	400	7.75
1004 MAKE SPOT WELD SPEC.,INSP	1.	300	100	7
1006 LOAD PARTS IN FIXTURE,weld, insp	0	300	600	13.5
1008 BOLT ASSEMBLE BULKHEAD	200	0	200	203
1009 CLEAN,IDENTIFY,INSPECT	0	200	200	6
1010 LONGERON				
1012 VERIFY MATERIAL	1.6	160	0	4
1014 NOTCH, SHEAR	0	0	160	2.4
1016 DEBURR,CLEAN, ALODINE	0	0	320	4.8
1017 IDENTIFY & INSPECT	0	160	0	2.4
1020 SHELL				
1022 VERIFY MATERIAL	30.	300	0	34.5
1024 ROUGH FACE, TURN,BORE	0	0	600	9
1026 AGE, INSPECT	0	50	0	0.75
1028 ROUGH FACE, TURN, BORE	0	0	600	9
1030 AGE, INSPECT	0	50	0	0.75
1032 FINISH FACE, TURN,BORE	0	0	1000	15
1034 DEBURR,CLEAN,ALODINE	2.5	0	400	8.5
1036 WEIGH, IDENTIFY, INSPECT	0	200	100	4.5
	236.1	1770	4680	332.85
LABOR COST (K$)		(26.55)	(70.2)	

FACILITIES

FACILITIES	TOTAL COST (K$)
500 CONSOLIDATED MANUFACTURING & ASSEMBLY PLANT	620

NEAR-TERM PRE-MANUFACTURING OPERATIONS

NON-RECURRING COSTS

ITEM	M/HRS	TOTAL COST (K$)
800 REVIEW PROGRAM DIRECTIVES	700.	10.5
810 MFG. PRELIMINARY SCHEDULES	420.	6.3
820 PRODUCIBILITY STUDIES	700.	10.5
830 IDENTIFY/ORDER LONG LEAD ITEMS	500.	7.5
840 ACCUMULATE/REVIEW ENGR & QC DOCUMENT.	1120.	16.8
850 DEVELOP SUB-ASSEMBLY & PARTS SCHEDULE	528.	7.92
860 MFG. PLANNING OPERATIONS	3200.	48
870 DESIGN/PROCURE TOOLING	1400.	21
880 VENDOR EVALUATION & SELECTION	1120.	16.8
NON-RECURRING TOTALS	9688	145.32

RECURRING COSTS

ITEM	M/HRS	TOTAL COST (K$)
900 EXPEDITE IN-HOUSE/PURCHASE PARTS	27500.	412.5
910 REVIEW PROGRESS WITH PROGRAM OFFICE	5500.	82.5
RECURRING TOTALS	33000	495

TOTAL RECURRING AND NON-RECURRING PRE-MFG. COSTS= 640.32

SUMMARY OF RESULTS

	MAT'L COST (K$)	Q.C. LABOR (M/HR)	MFG. LABOR (M/HR)	PRE-MFG. LABOR (M/HR)	TOTAL COST (K$)
TOOLING					381.5
FACILITIES					620
PRE-MANUFACTURING					
NON-RECURRING COST				9688	145.32
RECURRING COST				33000	495
MFG. PROCESSES	236.1	1770	4680		332.85
	236.1	1770	4680	42688	1974.67
LABOR IN (K$)		(26.55)	(70.2)		

5.5 MANUFACTURING LINE DIFFERENCES

The manufacturing line and facility differences starting with the state-of-the-art manufacturing Line (Line 1), progressing to the Improved Manufacturing Line (Line 2) and ending with the Advanced Manufacturing Line (Line 3) are shown for the 2- and 20-per year production rates for each of the structural elements in Tables 5-28 and 5-29.

Alternate differences for consideration as the study progresses include, for structural Element 2, the cost, quality, buy-off, and feasibility of rolling the entire cylinder section from an aluminum billet and the use of a diffusion bonded structure to replace the bonded honeycomb in the common bulkhead.

Differences between one manufacturing line and another may not necessarily reduce cost but may indicate a worthwhile trade-off of overall cost versus quality. For example, changing the manufacturing process of the fuel tank domes from welded segments to a total dome which is made by a shear spinning process from a single piece of metal may not result in a cost reduction; however, quality is certainly improved by the elimination of 150 feet of welds that must be ground smooth, X-rayed, dye penetrant inspected, and pressure tested for leakage. These requirements alone indicate the impact on quality by the elimination of welding.

Table 5-28

Structures Element No. 1, Manufacturing Line Differences

Item	State-of-the-Art Mfg Line Line 1		Improved Mfg Line Line 2		Advanced Mfg Line Line 3	
Production Rate ⟶	2 Per Year	20 Per Year	2 Per Year	20 Per Year	2 Per Year	20 Per Year
Skin	Roll-Form 4 Pieces	Same	Roll-Form 4 Pieces	Stretch Form Size From 1 Piece Roll		
Longeron	Brake-Form Saw Notch Joggle	Use Extrusion Punch Notch Joggle	Brake-Form Saw Notch Joggle	Use Extrusion Joggle, Notch (Shear Combination, Die, Punch Die)	N/C Machined Complete From Roll Forging Spot-Weld Assembly Longerons	
Rings	Mach From 1 Piece Forging	Mach From Multiple Piece Forging	Mach From Multiple Piece Forging	Same		
Honeycomb Bulkhead	Bonded Honeycomb	Same	Same	Same	Ambient Pressure and Temperature Bonding	
Assembly	Rivet	Same	Roll-Spot Weld	Same	See Above	See Above
Facilities Consolidated Plant - Shared with Other Programs	X	X	X	X	X	X

X = Yes

Table 5-29

Structures Element No. 2, Manufacturing Line Differences

Item	State-of-the-Art Mfg Line Line 1		Improved Mfg Line Line 2		Advanced Mfg Line Line 3	
Production Rate ⟶	2 Per Year	20 Per Year	2 Per Year	20 Per Year	2 Per Year	20 Per Year
Domes (4)	Stretch Formed Welded Gores (9 Gores/Dome)	Same	Spin Formed	Spin Formed	Spin Formed	Spin Formed
Rings (4)	Stretch Formed Segments (4 per Ring) Welded*	Same Welded	Same Welded	Same Welded	Same (Improved) Welded	Same (Improved) Welded
Common Bulkhead	Bonded Honeycomb	Same	Same	Same	Same	Same
Tank Cylinder	Machine Milled Brake Formed Segments (7) Welded	Same Welded	Same Welded	Same Welded	Same (Improved) Welded	Machine Milled Brake Formed Segments (4) (Improved) Welded
Assembly Cylinder to LOX Tank; Cylinder to Upper Dome; Jamb Ring Dollar	Welded	Welded	Welded	Welded	(Improved) Welded	(Improved) Welded
Facilities Fabrication Plant Assembly Plant Consolidated Plant	 Yes Yes —	 Yes Yes —	 — — Yes	 — — Yes	 — — Yes	 — — Yes

*State of the Art Welding Unless Otherwise Noted.

SECTION 6

INTERACTION ANALYSIS

6.1 INTRODUCTION

The previous chapters have presented the approach, results and details of the study calculations. It is evident from these results that the factors influencing manufacturing cost are numerous and varied; some of the more important factors are illustrated in Figure 6-1. These factors were varied using the methods described in earlier sections and the impact on cost results analyzed. Results for variation of factors one at a time and for several variables simultaneously are presented in Section 3.

The results with multiple factor variation can be categorized into two classifications:

a. Independent (or uncorrelated) factors.

b. Dependent (correlated) factors.

In the first case where manufacturing factors are independent, the MANCAN computer program was used for simple analysis with multiple factors. Those factors shown in Table 3-14 were initially assumed to be generally in this category, e.g., the factor 4, producibility file,is assumed independent of factor 7 for shop scheduling. The interactions which do exist between these factors are qualitative in nature and are discussed in Paragraph 6.4.

For purposes of this interaction analysis, the selected factors numbers 4, 5, and 8 which had the greatest impact on cost as illustrated in Figure 3-7, were grouped under one category, Factors. These together with seven of the other most significant parameters were selected for a quantitative interaction study:

	Parameter	Symbol
1.	Structural Element Type (Number 1 or Number 2)	E
2.	Manufacturing Line Number (Number 1 or Number 3)	N
3.	Manufacturing Rate (2 per Year or 20 per Year)	A
4.	Quantity (10 or 100)	Q
5.	Inclusion of Tax and Interest (0 or 3 percent, 6 percent)	T

Parameters	Symbol
6. Type of Depreciation (100 percent or straight line)	D
7. Learning Curve (100 percent or 80 percent)	L
8. Factors (0 or number 4, number 5, number 8)	F

As discussed in the Results, Section 3, the indicated excursions in these eight parameters have the most significant impact on manufacturing costs. These parameters are decidedly interrelated and formed the basis of the quantitative interactions study. This study and results are discussed in the following section.

6.2 QUANTITATIVE INTERACTIONS STUDY

6.2.1 METHODS

Several methods were considered for associating quantitative values with the interactions between the major variables. These methods include:

a. Parametric Study—varying parameters singly and in combinations.
b. Multiple Regression—fitting a least-squares surface through the results and examining the covariance coefficients.
c. Factorial Design (two-level 2^8 design) where all combinations of two versions of each of 8 variables were studied simultaneously.

By far, the most productive yet conventional approach was the parametric study. Results from this type of investigation are presented thoroughly in Section 3 and Appendix B. The two disadvantages are: (a) the high cost for obtaining the necessary data points (numbered in the tens of thousands), and (b) the difficulty in presenting interaction results. With the limitations of graph paper and matrices, one is hard-pressed to present or absorb results of the simultaneous variation of more than three or four variables.

6.2.2 MULTIPLE REGRESSION

Multiple regression techniques were applied using an available computer program (MRFG)[13] from the General Electric timesharing library. Initial runs were used to fit the following model to a series of available observations:

$$Y - \overline{Y} = (X_1 - \overline{X}_1)\beta_1 + (X_2 - \overline{X}_2)\beta_2 + \ldots + (X_p - \overline{X}_p)\beta_p$$

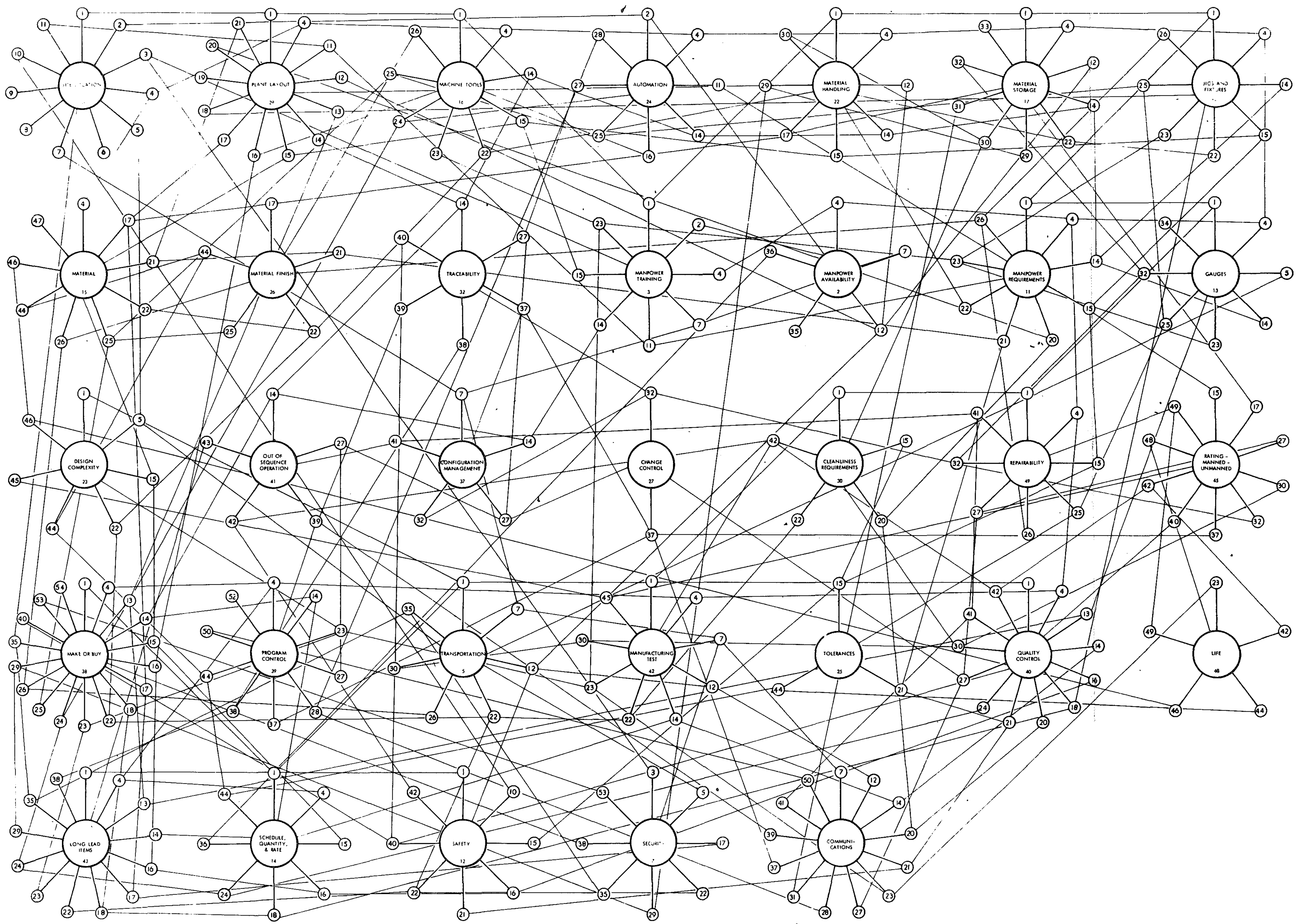


Figure 6-1. Complexity of Manufacturing Processes

where:

a. X_j (j = 1 ... p) were selected values of the independent variables such as depreciation, taxes and interest percent, inclusion of factors, learning curve slope and manufacturing rate.

b. Y is the cost per unit in K$.

c. The bar superscript indicates the mean values of each variable.

The multiple correlation coefficient ρ_m was determined where $0 < \rho_m \leq 1$. Least squares estimates of coefficients ($\beta_1 \ldots \beta_p$) were determined as well as the constant term, b_o, where

$$b_o = y - \sum_{i=1}^{p} X_1 \beta_1$$

Additional statistical parameters, including the variance-covariance matrix were computed to determine the impact of interrelationships of variables.

The initial runs, which used variables assumed to be directly (and linearly) correlated to cost, were generally inappropriate. As is evident from inspection of typical results in Appendix B, the costs do not vary linearly with the various parameters.

Several transformations of variables were considered, but these did not improve results greatly, although the multiple correlation coefficient did improve from 0.628 to 0.891 in the best case. In this (best) case for element number 2, line number 1, 20 per year rate, the following transforms were used,

X_1 = 100/quantity produced

X_2 = 1/program length in years

The equation relating other variables was as follows:

$$\text{K\$ Cost per unit} = 18,800\,(X_1) + 96849\,(X_2) + 7.68\,(\text{Learning Curve}) - 980\,(\text{Tax Number}) - 8685.$$

In this case, the learning curve value was either 1.0 or 0.8, and the tax and interest number was 2 for 3 percent and 6 percent, and 1 for 0 taxes and interest.

The results, however, were of little value in determining the interactions between variables. Including a greater number of variables in the analyses only served to reduce the multiple correlation coefficients. Attention was then focused on a more comprehensive factorial design analysis described below.

6.2.3 FACTORIAL DESIGN DATA

Factorial design analysis, as described in References 14 and 15 examines all first-order combinations of selected experimental factors. For simultaneous study of two values of each factor, the number of data points required is 2^K where K is the number of factors studied, in this case 8. To minimize the number of required computer runs, equations were developed which provided a reasonabley good fit through the data by approximating the detailed calculations performed by the computer, by,

$$C = \sum_{i=1}^{n} t_i d_i \ell_i f_i G_i + R$$

where

C is the cost for a particular set of conditions, e.g., structural element, rate and quantity

t is a coefficient for inclusion of taxes and interest

and is $\begin{cases} 0 & \text{for nominal case (no taxes or interest)} \\ 1 & \text{for inclusion of 3 percent taxes and 6 percent interest} \end{cases}$

d is a coefficient for variation of depreciation method

and is $\begin{cases} 1 \text{ for 100 percent writeoff} \\ \text{assigned value } < 1 \text{ for straight line} \end{cases}$

ℓ is a coefficient for inclusion of learning curve

and is $\begin{cases} 1 \text{ for learning curve of 100 percent} \\ \text{assigned value } < 1 \text{ for 80 percent learning curve} \end{cases}$

f is a coefficient for inclusion of factors

and is $\begin{cases} 1 \text{ for no factors} \\ \text{assigned value } < 1 \text{ when factors are included} \end{cases}$

G is the cost for a subgroup of costs which comprise the total cost, C

R is the remainder

n = total numbers of subgroups

For example, for element number 2, line number 1, 20 per year and a 5 year program, the values shown in Table 6-1 are applicable.

Table 6-1

Cost Equation Factors

i	Types of Cost Subgroup	G_i	t_i	d_i	ℓ_i	f_i
1	Taxes and Interest	14548	1, 0	1, .975	1, 1	1, .795
2	Pre-Manufacturing Labor (R)	1500	1, 1	1, 1	1, .3265	1, .65
3	Manufacturing Labor	11305	1, 1	1, 1	1, .3265	1, .65
4	Quality Control Labor	6641	1, 1	1, 1	1, .3265	1, .504
5	Material	14182	1, 1	1, 1	1, 1	1, .504
6	NR Pre-Manufacturing Labor	1040	1, 1	1, 1	1, 1	1, .64
7	Facilities	22833	1, 1	1, .125	1, 1	1, .81
8	Tooling	9496	1, 1	1, .55	1, 1	1, .75
	Remainder (R)	390				
	Total	81936				

The values in column G_i for this example are the same as the second column of Table 3-6. The selection of the two values for the coefficients t_i, d_i, ℓ_i, and f_i is determined by inclusion of the factors in the equation.

Tables similar to 6-1 were constructed for the other cases, equivalent to Tables 3-3 through 3-6. A small time-sharing computer program was developed to rapidly compute the needed values listed in Table 6-2 for use in the factorial design analysis. Checking of these results against known results indicated that this equation approximated the actual results within a few percent.

6.2.4 FACTORIAL DESIGN ANALYSIS

In a 2^K factorial design, that is, a two-level factorial design in K variables, data is analyzed for all combinations of two versions of each of the K variables. If the variable is continuous, the two versions are the high and low level of that variable. If the variable is qualitative, as in the case of the majority of the factors studied here, the two versions correspond to two types or the presence or absence of the variable.

Table 6-2

Data for $(2)^7$ Factorial Design

E	N	R	Q	T	D	L	F	K$ Cost/ Unit	% Relative to Line #1, 2/Year
2	1	2	10	1	1	1	1	2354.7	133.972
2	1	2	10	1	1	1	0	1847.49	105.115
2	1	2	10	1	1	1	1	2354.7	133.972
2	1	2	10	1	1	1	0	1847.49	105.115
2	1	2	10	1	0	1	1	1347.86	76.6875
2	1	2	10	1	0	1	0	1033.07	58.7772
2	1	2	10	1	0	1	1	1347.86	76.6875
2	1	2	10	1	0	1	0	1033.07	58.7772
2	1	2	10	0	1	1	1	1761.5	100.222
2	1	2	10	0	1	1	0	1343.27	76.4265
2	1	2	10	0	1	1	1	1761.5	100.222
2	1	2	10	0	1	1	0	1343.27	76.4265
2	1	2	10	0	0	1	1	769.49	43.7807
2	1	2	10	0	0	1	0	541.454	30.8064
2	1	2	10	0	0	1	1	769.49	43.7807
2	1	2	10	0	0	1	0	541.454	30.8064
2	3	2	10	1	1	1	1	2305.8	131.19
2	3	2	10	1	1	1	0	1812.3	103.112
2	3	2	10	1	1	1	1	2305.8	131.19
2	3	2	10	1	1	1	0	1812.3	103.112
2	3	2	10	1	0	1	1	1402.12	79.7744
2	3	2	10	1	0	1	0	1082.51	61.59
2	3	2	10	1	0	1	1	1402.12	79.7744
2	3	2	10	1	0	1	0	1082.51	61.59
2	3	2	10	0	1	1	1	1713.2	97.4738
2	3	2	10	0	1	1	0	1308.59	74.4529
2	3	2	10	0	1	1	1	1713.2	97.4738
2	3	2	10	0	1	1	0	1308.59	74.4529
2	3	2	10	0	0	1	1	824.33	46.9009
2	3	2	10	0	0	1	0	591.389	33.6475
2	3	2	10	0	0	1	1	824.33	46.9009
2	3	2	10	0	0	1	0	591.389	33.6475
1	1	2	10	1	1	1	1	143.4	131.079
1	1	2	10	1	1	1	0	110.805	101.284
1	1	2	10	1	1	1	1	143.4	131.079
1	1	2	10	1	1	1	0	110.805	101.284
1	1	2	10	1	0	1	1	82.2275	75.1622
1	1	2	10	1	0	1	0	61.2821	56.0166
1	1	2	10	1	0	1	1	82.2275	75.1622
1	1	2	10	1	0	1	0	61.2821	56.0166
1	1	2	10	0	1	1	1	109.5	100.091
1	1	2	10	0	1	1	0	81.99	74.9452
1	1	2	10	0	1	1	1	109.5	100.091

Table 6-2

Data for $(2)^7$ Factorial Design (Cont.)

E	N	R	Q	T	D	L	F	K$ Cost/ Unit	% Relative to Line #1, 2/Year
1	1	2	10	0	1	1	0	81.99	74.9452
1	1	2	10	0	0	1	1	49.175	44.9497
1	1	2	10	0	0	1	0	33.1875	30.3359
1	1	2	10	0	0	1	1	49.175	44.9497
1	1	2	10	0	0	1	0	33.1875	30.3359
1	3	2	10	1	1	1	1	171.3	156.581
1	3	2	10	1	1	1	0	135.352	123.722
1	3	2	10	1	1	1	1	171.3	156.581
1	3	2	10	1	1	1	0	135.352	123.722
1	3	2	10	1	0	1	1	98.7325	90.2491
1	3	2	10	1	0	1	0	76.6991	70.1089
1	3	2	10	1	0	1	1	98.7325	90.2491
1	3	2	10	1	0	1	0	76.6991	70.1089
1	3	2	10	0	1	1	1	126.2	115.356
1	3	2	10	0	1	1	0	97.017	88.681
1	3	2	10	0	1	1	1	126.2	115.356
1	3	2	10	0	1	1	0	97.017	88.681
1	3	2	10	0	0	1	1	54.76	50.0548
1	3	2	10	0	0	1	0	39.3225	35.9438
1	3	2	10	0	0	1	1	54.76	50.0548
1	3	2	10	0	0	1	0	39.3225	35.9438
2	1	20	100	1	1	1	1	819.35	46.6175 *
2	1	20	100	1	1	1	0	570.56	32.4625 *
2	1	20	100	1	1	0	1	688.381	39.166 *
2	1	20	100	1	1	0	0	491.961	27.9905 *
2	1	20	100	1	0	1	1	573.192	32.6122 *
2	1	20	100	1	0	1	0	373.791	21.2671 *
2	1	20	100	1	0	0	1	442.223	25.1606 *
2	1	20	100	1	0	0	0	295.191	16.7951 *
2	1	20	100	0	1	1	1	673.87	38.3404
2	1	20	100	0	1	1	0	454.904	25.8821
2	1	20	100	0	1	0	1	542.901	30.8888
2	1	20	100	0	1	0	0	376.304	21.4101
2	1	20	100	0	0	1	1	431.349	24.5419
2	1	20	100	0	0	1	0	261.026	14.8513
2	1	20	100	0	0	0	1	300.38	17.0904
2	1	20	100	0	0	0	0	182.426	10.3793
2	3	20	100	1	1	1	1	705.63	40.1474
2	3	20	100	1	1	1	0	488.216	27.7774
2	3	20	100	1	1	0	1	594.435	33.8208
2	3	20	100	1	1	0	0	420.932	23.9493
2	3	20	100	1	0	1	1	506.79	28.8342
2	3	20	100	1	0	1	0	330.188	18.7863
2	3	20	100	1	0	0	1	395.595	22.5077

*Values used in example in Figure 6-2 and Table 6-5.

Table 6-2

Data for $(2)^7$ Factorial Design (Cont.)

E	N	R	Q	T	D	L	F	K$ Cost/ Unit	% Relative to Line #1, 2/Year
2	3	20	100	1	0	0	0	262.905	14.9582
2	3	20	100	0	1	1	1	580.81	33.0456
2	3	20	100	0	1	1	0	388.984	22.1315
2	3	20	100	0	1	0	1	469.615	26.7191
2	3	20	100	0	1	0	0	321.7	18.3034
2	3	20	100	0	0	1	1	385.09	21.91
2	3	20	100	0	0	1	0	233.437	13.2816
2	3	20	100	0	0	0	1	273.895	15.5835
2	3	20	100	0	0	0	0	166.153	9.45343
1	1	20	100	1	1	1	1	25.1	22.9433
1	1	20	100	1	1	1	0	17.0823	15.6146
1	1	20	100	1	1	0	1	19.6177	17.9321
1	1	20	100	1	1	0	0	13.5631	12.3977
1	1	20	100	1	0	1	1	19.1118	17.4696
1	1	20	100	1	0	1	0	12.262	11.2084
1	1	20	100	1	0	0	1	13.6295	12.4584
1	1	2P	100	1	0	0	0	8.74272	7.99152
1	1	20	100	0	1	1	1	21.83	19.9543
1	1	20	100	0	1	1	0	14.4827	13.2383
1	1	20	100	0	1	0	1	16.3477	14.9431
1	1	20	100	0	1	0	0	10.9634	10.0214
1	1	20	100	0	0	1	1	15.9235	14.5553
1	1	20	100	0	0	1	0	9.7273	8.8915
1	1	20	100	0	0	0	1	10.4412	9.54407
1	1	20	100	0	0	0	0	6.20807	5.67465
1	3	20	100	1	1	1	1	24.25	22.1664
1	3	20	100	1	1	1	0	17.3905	15.8963
1	3	20	100	1	1	0	1	20.2629	18.5218
1	3	20	100	1	1	0	0	14.8254	13.5516
1	3	20	100	1	0	1	1	16.9935	15.5334
1	3	20	100	1	0	1	0	11.6176	10.6194
1	3	20	100	1	0	0	1	13.0064	11.8888
1	S	20	100	1	0	0	0	9.0525	8.27468
1	3	20	100	0	1	1	1	19.75	18.053
1	3	20	100	0	1	1	0	13.813	12.6262
1	3	20	100	0	1	0	1	15.7629	14.4085
1	3	20	100	0	1	0	0	11.2479	10.2815
1	3	20	100	0	0	1	1	12.606	11.5229
1	3	20	100	0	0	1	0	8.12952	7.43101
1	3	20	100	0	0	0	1	8.61888	7.87832
1	3	20	100	0	0	0	0	5.56444	5.08633

For the eight variables under discussion the levels shown in Table 6-3 were arbitrarily selected, which correspond to -1 and +1 values respectively.

Table 6-3

Selected Two-Level Values for Variables

Variable	Symbol	Low Level (-1)	High Level (+1)
Structural Element Type	E	#2	#1
Manufacturing Line Number	N	#1	#3
Manufacturing Rate	A	2/Year	20/Year
Quantity	Q	5 Years Production	—
Taxes and Interest	T	0	3%, 6%
Depreciation	D	100%	Straight Line
Learning Curve	L	100%	80%
Factors	F	None	#4, 5, 8

The data grouping for analysis is arranged to accommodate systematic analysis of results. For example, grouping of the eight runs comprising a 2^3 factorial are illustrated in Table 6-4 for three variables, F, L and D.

Table 6-4

Notations for a 2^3 Factorial Design

Sequence Number	Variables	Notation		
		F	L	D
1	1	-1	-1	-1
2	F	+1	-1	-1
3	L	-1	+1	-1
4	FL	+1	+1	-1
5	D	-1	-1	+1
6	FD	+1	-1	+1
7	LD	-1	+1	+1
8	FLD	+1	+1	+1

Continuing this illustration, a 2^3 example is selected for element number 2, line number 1, 20 per year from the middle of Table 6-2 (noted by asterisks) and illustrated in a cube in Figure 6-2. The eight corners correspond to the notations in Table 6-4; the values at each corner are the percent cost. Varying the depreciation (D) from 100 percent to straight line shows an average decrease from the values on the back face of the cube of (47 + 32 + 39 + 28 = 146) to the front face of (33 + 21 + 25 + 17 = 96) or an average change of -50/4 or -12.5. In the same manner, the change in learning (L) compares the left face (47 + 33 + 32 + 21 = 133) with the right (39 + 28 + 25 + 17 = 109) or an average change of -24/4 = -6. Average impact of inclusion of factors (F) is seen by comparing the lower surface (47 + 33 + 39 + 25 = 144) with the upper surface of the cube (32 + 21 + 28 + 17 = 98) or an average of -46/4 or -11.5.

In the same manner the interactions (combined impact of two and three variables simultaneously) are determined by the comparison of the values at the plane intersections for the combined variables. Results for this case are tabulated in Table 6-5, and can be expressed in the following equation, with coefficients halved for use with the selected coordinate system.

$$\text{Percent Cost/Unit} = -5.75\,(F) - 3\,(L) + 1\,FL - 6.25\,D + 0.75\,FD + 30.25$$

where the values of F, L, and D have a value of either -1 or + 1 as illustrated in Table 6-3. The constant value 30.25 is the numerical average of all points.

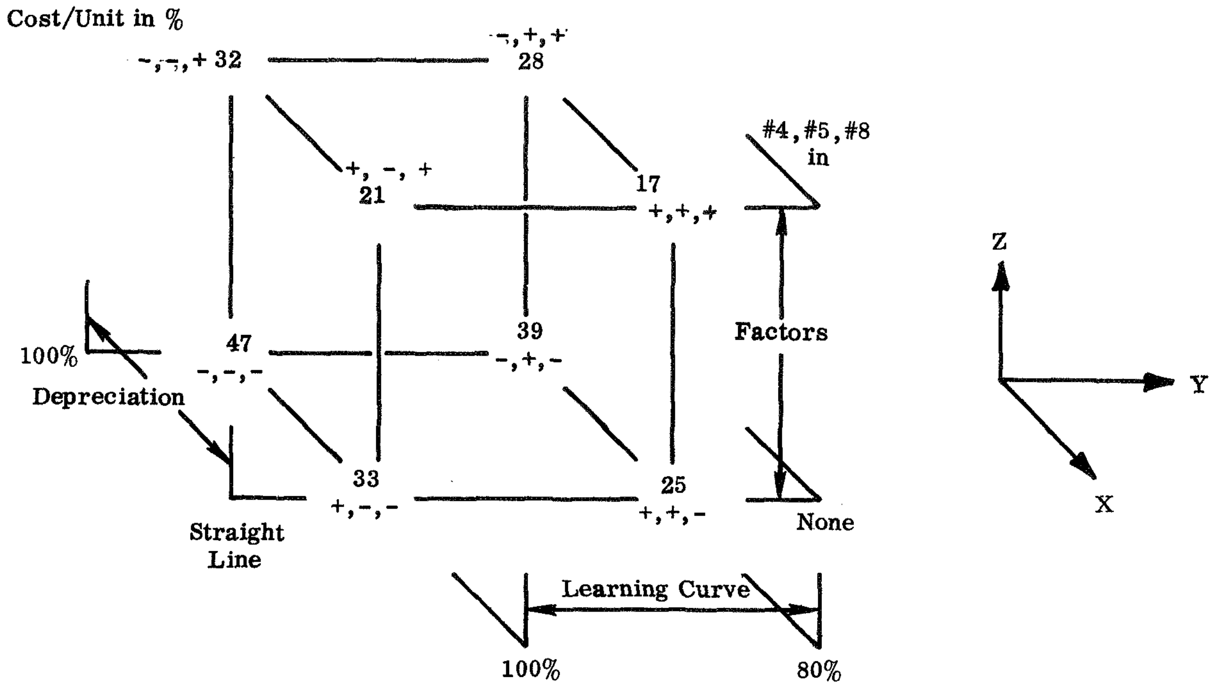
Table 6-5

Results for the 2^3 Example in Figure 6-2

COEF.	VARIABLES	MEAS. VALUE
-11.5	F	32
-6	L	39
2	FL	28
-12.5	D	33
1.5	FD	21
0	LD	25
0	FLD	17
30.25	CONSTANT	

Constant Conditions

Element	Line	Rate	Q	Taxes & Interest
2	1	20	20	No



Diagrammatic Representation of Calculated Costs Per Unit in %

For all Combinations of Two Versions of Each of Three Variables (Depreciation, Learning Curve and Factors).

Figure 6-2. The 2^3 Factorial Design Array

Interpretation of the absolute value of the coefficients shows the average impact of the variables on cost. In this example the primary impact comes from D, F, and L in that order followed by the interactions FL and FD which are less important.

Analyses of the 2^7 factorial design data in Table 6-2 yields the results in Table 6-6. In this example the differences between structural elements are normalized by referring all percentages to line number 1, 2 per year production rate, without taxes and interest. The production is for 5 years, e.g. , 10 units for 2 per year and 100 units for 20 per year.

The equation, including only the coefficients larger than 0.5 from Table 6-6 (halved for the coordinate system) and rounding off the decimals, is as follows:

$$
\begin{aligned}
\text{Percent Cost} = & - 7.2\,(F) - 1.1\,(L) - 15.1\,(D) + 1.7\,(FD) - 9.4\,(T) \\
& + 0.9\,(FT) + 1.5\,(N) - 1.4\,(E) + 2\,(NE) - 1.3\,(DNE) \\
& - 0.9\,(TNE) - 31.2\,(A) + 3.7\,(FA) - 1.1\,(LA) \\
& + 10.7\,(DA) - 1\,(FDA) + 6.7\,(TA) - 2.3\,(NA) \\
& + 0..6\,(TNA) - 4.3\,(EA) + 0.7\,(FEA) + 1.6\,(DEA) \\
& + 0.8\,(TEA) - 1.6\,(NEA) + 0.6\,(DNEA) + 50.
\end{aligned}
$$

The largest impact on manufacturing cost is found in the single parameters,

Manufacturing Rate (A)	-31.2
Depreciation (D)	-15.1
Taxes and Interest (T)	- 9.4
Factors 4 + 5 + 8 (F)	- 7.2

The parameter interactions of greatest significance are the following combinations,

Depreciation and Rate (DA)	+10.7
Taxes and Rate (TA)	+ 6.7
Element and Rate (EA)	- 4.3
Factors and Rate (FA)	+ 3.7

and combinations of less importance,

FD, FT, NE, DNE, TNE, LA, FDA, NA, TNA, FEA, DEA, TEA, NEA, and DNEA.

A significant factor in the above analyses was the introduction of two values of rate (A). Since this introduces a significant change in line tooling and processes, it is significant to look at the impact of the other variables without this overshadowing effect. An example of a 2^6 design for 20 per year only is shown in Table 6-7.

Table 6-6

Results of $(2)^7$ Factorial Design Analysis

Coefficient	Variables	Measurement Value
-14.3594	F	105
-2.26562	L	134
0.421875	FL	105
-30.2656	D	77
3.48437	FD	59
0.015625	LD	77
-0.046875	FLD	59
-18.8281	T	100
1.85937	FT	76
0.015625	LT	100
-0.109375	FLT	76
0.015625	DT	43
0.203125	FDT	30
0.046875	LDT	43
-0.078125	FLDT	30
3.04687	N	131
-0.078125	FN	103
0.265625	LN	131
-0.046875	FLN	103
-0.046875	DN	80
-0.296875	FDN	62
-0.015625	LDN	80
0.046875	FLDN	62
-0.984375	TN	97
-0.171875	FTN	74
-0.015625	LTN	97
0.109375	FLTN	74
0.296875	DTN	47
-0.265625	FDTN	34
0.078125	LDTN	47
0.078125	FLDTN	34
-2.72687	E	131
0.453125	FE	101
0.484375	LE	131
-0.078125	FLE	101
0.046875	DE	75
-0.328125	FDE	56
0.015625	LDE	75
0.078125	FLDE	56
0.734375	TE	100
-0.328125	FTE	75
0.015625	LTE	100
0.140625	FLTE	75
0.328125	DTE	45

Table 6-6

Results of $(2)^7$ Factorial Design Analysis (Cont.)

Coefficient	Variables	Measurement Value
-0.359375	FDTE	30
0.046875	LDTE	45
0.046875	FLDTE	30
3.98437	NE	157
0.109375	FNE	124
0.015625	LNE	157
-0.046875	FLNE	124
-2.60937	DNE	20
0.515625	FDNE	70
-0.015625	LDNE	20
-0.078125	FLDNE	70
-1.79687	TNE	115
0.515625	FTNE	89
-0.015625	LTNE	115
-0.140625	FLTNE	89
-0.265625	DTNE	50
0.296875	FDTNE	36
0.078125	LDTNE	50
-0.046875	FLDTNE	36
-62.3594	A	47
7.39062	FA	32
-2.26562	LA	39
0.421875	FLA	28
21.4844	DA	33
-2.01562	FDA	21
0.015625	LDA	25
-0.046875	FLDA	17
13.2969	TA	38
-0.765625	FTA	26
0.015625	LTA	31
-0.109375	FLTA	21
-0.359375	DTA	15
0.328125	FDTA	17
0.046875	LDTA	10
-0.078125	FLDTA	10
-4.57812	NA	40
0.046875	FNA	28
0.265625	LNA	34
-0.046875	FLNA	24
0.828125	DNA	29
-0.421875	FDNA	19
-0.015625	LDNA	23
0.046875	FLDNA	15
1.26562	TNA	33
-0.421875	FTNA	22

Table 6-6

Results of $(2)^7$ Factorial Design Analysis (Cont.)

Coefficient	Variables	Measurement Value
-0.015625	LTNA	27
0.109375	FLTNA	18
0.046875	DTNA	22
-0.265625	FDTNA	13
0.078125	LDTNA	16
0.078125	FLDTNA	9
-8.54687	EA	23
1.45312	FEA	16
0.484375	LEA	18
-0.078125	FLEA	12
3.29687	DEA	17
-0.578125	FDEA	11
0.015625	LDEA	12
0.078125	FLDEA	8
1.60937	TEA	20
-0.453125	FTEA	13
0.015625	LTEA	15
0.140625	FLTEA	10
0.203125	DTEA	15
-0.234375	FDTEA	9
0.046875	LDTEA	10
0.046875	FLDTEA	6
-3.14062	NEA	22
0.484375	FNEA	16
0.015625	LNEA	19
-0.046875	FLNEA	14
1.26562	DNEA	16
0.140625	FDNEA	11
-0.015625	LDNEA	12
-0.078125	FLDNEA	8
0.703125	TNEA	18
0.265625	FTNEA	13
-0.015625	LTNEA	14
-0.140625	FLTNEA	10
-0.265625	DTNEA	11
0.296875	FDTNEA	7
0.078125	LDTNEA	8
-0.046875	FLDTNEA	5
49.9453	CONSTANT	

Table 6-7

Elements 1 and 2—20 per Year Values as Percent of Nominal

Coefficient	Variables	Measurement Value
-25.5625	F	85
-16.125	L	102
3.625	FL	73
-28.25	D	85
3.125	FD	55
-0.0625	LD	66
-0.0625	FLD	44
-16.6875	T	100
2.0625	FT	68
0	LT	81
-0.125	FLT	56
0.25	DT	64
0	FDT	39
-0.1875	LDT	45
-0.0625	FLDT	027
-6.25	N	105
2.125	FN	72
2.0625	LN	88
-0.4375	FLN	62
0.3125	DN	75
-0.0625	FDN	49
0	LDN	59
0	FLDN	39
-0.625	TN	86
0.125	FTN	58
0.0625	LTN	70
0.1875	FLTN	48
-0.0625	DTN	57
-0.0625	FDTN	35
0	LDTN	41
0.125	FLDTN	25
0.5	E	115
0.125	FE	78
-1.8125	LE	90
0.1875	FLE	62

Table 6-7

Elements 1 and 2—20 per Year Values as Percent of Nominal (Cont.)

Coefficient	Variables	Measurement Value
1.1875	DE	88
-0.1875	FDE	56
-0.25	LDE	62
0	FLDE	40
0.875	TE	100
-0.125	FTE	66
-0.0625	LTE	75
0.0625	FLTE	50
0.0625	DTE	73
0.0625	FDTE	46
0	LDTE	48
-0.125	FLDTE	28
2.6875	NE	111
0.5625	FNE	80
0.875	LNE	93
-0.125	FLNE	68
-3	DNE	78
0.125	FDNE	53
0.0625	LDNE	60
0.0625	FLDNE	41
-2.0625	TNE	90
0.1875	FTNE	63
0	LTNE	72
0.125	FLTNE	52
0	DTNE	58
0	FDTNE	37
-0.0625	LDTNE	39
0.0625	FLDTNE	25
65.2812	CONSTANT	

Here the impact of learning curve (L) is more pronounced, both as single and multiple variable interactions. The impact of the factors (F) is more pronounced and differences between the two elements are less noticeable at the single (20 per year) rate.

6.3 SUMMARY OF QUANTITATIVE INTERACTIONS STUDY

The foregoing results as summarized from Table 6-6 on Figure 6-3 illustrate the strong impact of the single variables, such as depreciation, rate, taxes and interest, selected factors, and learning. Interactions of combined variables on results are less pronounced, though still quite significant, particularly those coupled with influence of changing manufacturing rate.

The interactions between the larger number of factors impacting manufacturing costs are discussed qualitatively in the next section.

6.4 QUALITATIVE INTERACTION STUDY

As shown in Figure 6-4, the major factors that control manufacturing cost are dependent upon each other and a change in one may start a chain reaction and impact several other factors to some degree.

A cost saving measure taken in one area may significantly increase cost in other areas resulting in an overall increase in manufacturing cost. For example, moving the manufacturing operation to a low tax location generally brings with it low cost facilities. However, these conditions might also necessitate moving key personnel into the area and implementing extensive training programs for utilization of the inexperienced available labor force. Learning on the job is costly; concurrent manufacturing errors result in increased component rework or scrap and material waste. Frequently under these conditions, lost time attributed to increased personnel injuries will multiply.

It is evident that each manufacturing or related factor change must be evaluated to determine total interaction impact upon overall cost. However, it is a considerable task to quantitatively evaluate the many changes in factors and their overall interactions.

A step in this direction is the matrix shown in Figure 3-7 which is applicable to the overall manufacturing and related system. This matrix is useful as a qualitative evaluation summary through the identification of factors interactions.

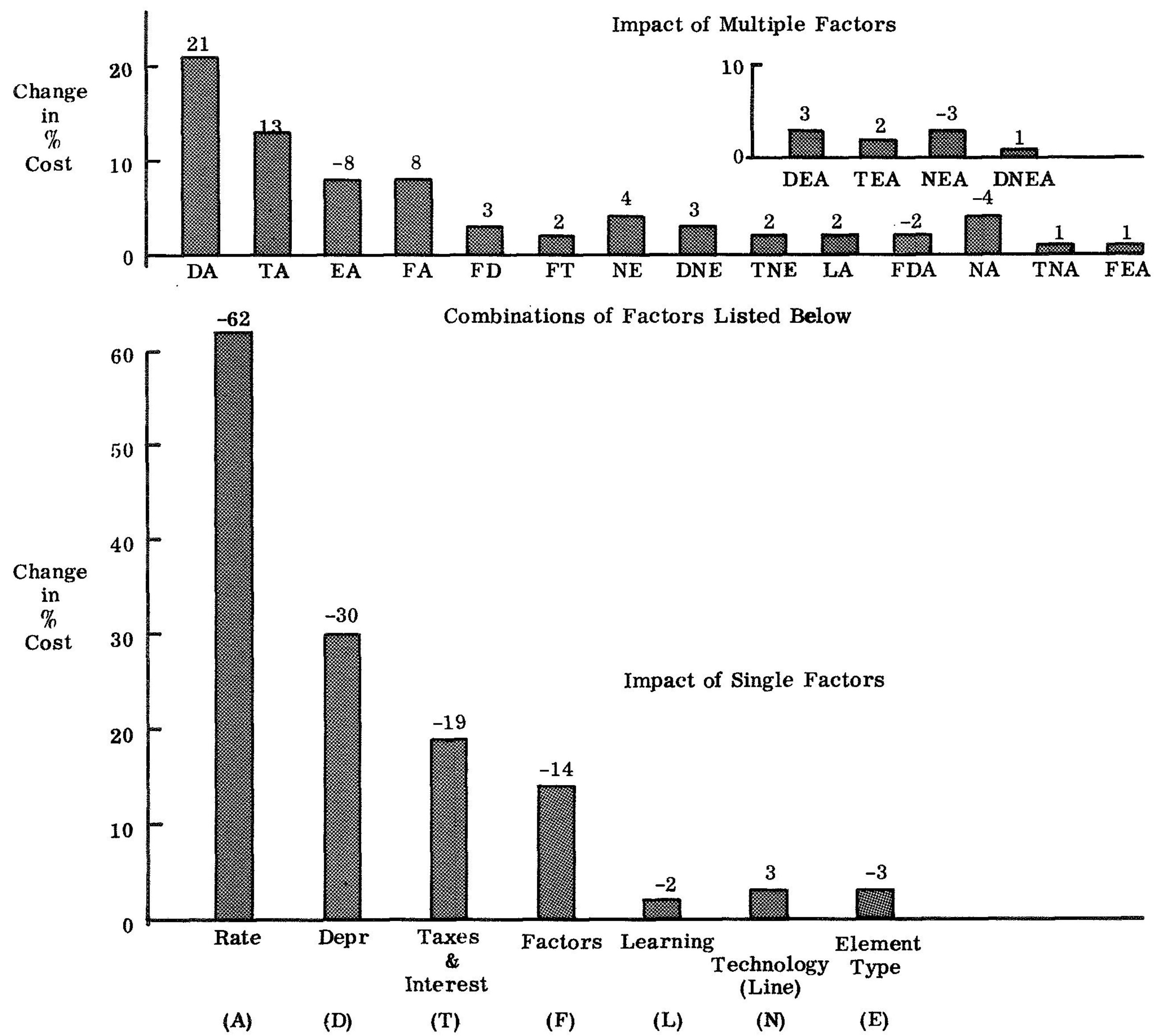


Figure 6-3. Results of 2^7 Factorial Design Averages

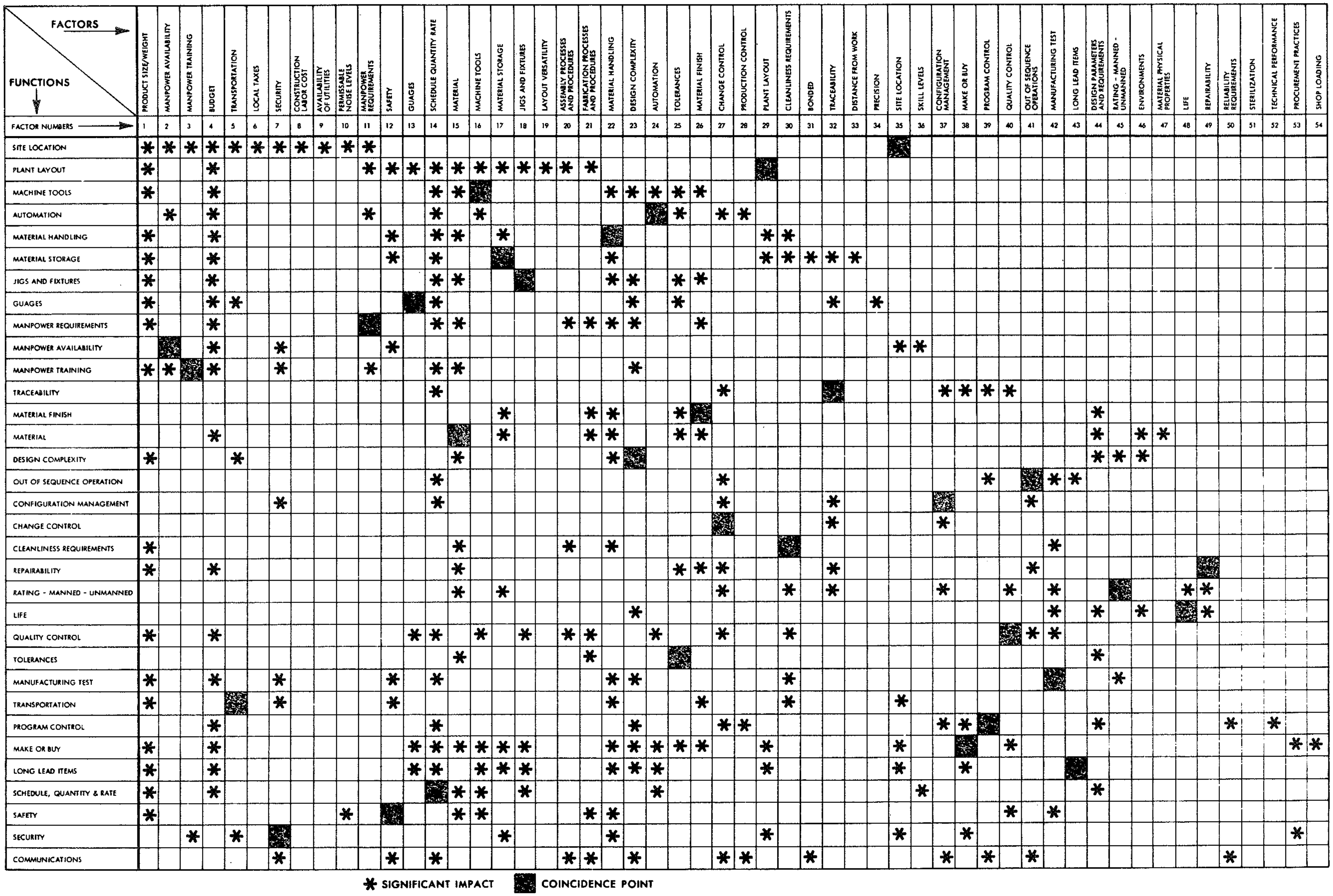


Figure 6-4. Interaction Matrix of Factors Influencing Manufacturing Cost

The key manufacturing parameters (which are major grouping of the factors shown in Figure 6-4) are shown in Figure 6-5 down the left side as well as across the bottom of this illustration. The factors which have a major influence of the key parameters, one-on-another, are shown in the field of Figure 6-5.

An example of the use of Figure 6-5 is seen in the dependence of both design and product identification factors upon manufacturing test and change control. A second example is seen in the dependence of program and quality control factors upon budget, schedule, and production rate. The principal impact of program control factors on quality will be influenced by available budget, schedules and planned production rate.

Other qualitative interaction factors relating to key manufacturing parameters can be seen in Figure 6-5.

	Value Engineering Interaction Factors	Manpower Interaction Factors	Program Control Interaction Factors	Product Identification Interaction Factors	Transportation Interaction Factors	Communications Interaction Factors	Plant Safeguard Interaction Factors	Quality Assurance Interaction Factors	Design Interaction Factors	Plant Facilities Interaction Factors
Value Engineering										
Manpower Factors	Make or Buy Decisions Long-Lead Items Skill Levels Automation									
Program Factors	Budget Make or Buy Alternate Decision Evaluation Long-Lead Items	Skill Levels Make or Buy Decisions Budget Long-Lead Items Schedule								
Product Identification Factors	Number and Schedule of Changes	Out of Sequence Operations Manpower Training	Schedule, Quantity, Rate Make or Buy Decisions Program Control Quality Control Change Control Configuration Management Long-Lead Items							
Transportation Factors	Simplified Methods, Location of Operations	Product Size and Weight Schedule, Quantity, Rate	Site Location Product Size and Weight Quantity Design Complexity	Out-of-Sequence Operations						
Communications	Communications Requirements	Manpower Training	Schedule, Quantity, and Rate Program Control	Change Control Configuration Management Out-of-Sequence Operations	Plant Location					
Safeguard Factors	Safety, Security Audits	Manpower Training Manpower Availability Skill Levels Automation	Make or Buy Decisions Quality Control Procurement Practices Program Control	Security, Safety } Requirements	Security, Safety } Requirements	Security, Safety } Requirements				
Quality Assurance Factors	Reliability Requirements Quality Requirements	Manpower Training	Budget Quality Control Schedule Quantity and Rate Sterilization Cleanliness Requirements Reliability Program Control	Change Control Traceability Configuration Management Out-of-Sequence Operations Manufacturing Tests	Cleanliness Requirements Life	Sterilization, Cleanliness Requirements	Cleanliness Requirements Manufacturing Test			
Design Factors	Technical Performance Materials Selection Cost Analysis	Product Size and Weight Material Design Complexity Material Finish Skill Levels Make or Buy Decisions Long-Lead Items	Budget Program Control Schedule, Quantity, Rate Long-Lead Items Make or Buy Manufacturing Test Safety Design Complexity Material Finish Design Parameters and Requirements Technical Requirements	Manufacturing Test Change Control	Product Size and Weight Design Complexity Material Finish Design Parameters and Requirements	Design Complexity	Product Size and Weight Safety	Product Size and Weight Repairability Quality Control Material Cleanliness Manned or Unmanned Tolerances Design Complexity Design Parameters and Requirements Environment		
Plant Facilities	Facilities, Tooling, Equipment Availability	Manpower Availability Manpower Training Manpower Requirements Material Handling Site Location Skill Levels Plant Layout	Budget Schedule, Rate, Quantity Gauges Make or Buy Long-Lead Items Program Control Machine Tools Material Storage Security Jigs and Fixtures Material Handling Automation Plant Layout Site Location Local Taxes Construction Labor Cost Fabrication Processes and Procedures Assembly Processes and Procedures	Traceability	Move Distance Product Size and Weight Transportation Material Handling Site Location	Bonded Facilities	Security Safety Machine Tools Material Handling Plant Layout Site Location Noise Level	Cleanliness Requirements Gauges Machine Tools Material Storage Jigs and Fixtures Material Handling Automation	Product Size and Weight Material Complexity Tolerances Material Finish Precision Material Storage Material Handling	
Manufacturing and Assembly Factors	Manufacturing Capability Fabrication Processes and Procedures Assembly Processes and Procedures Subcontract Policies	Assembly Processes and Procedures Fabrication Processes and Procedures Manpower Requirements Manpower Availability Manpower Training Manpower Skills Shop Loading	Production Control Shop Loading Program Control	Assembly Processes and Procedures Fabrication Processes and Procedures Out-of-Sequence Operations	Product Size and Weight	Assembly Processes and Procedures Fabrication Processes and Procedures Production Control	Fabrication Processes and Procedures Assembly Processes and Procedures	Assembly Processes and Procedures Fabrication Processes and Procedures	Fabrication Processes and Procedures Assembly Processes and Procedures	Assembly Processes and Procedures Fabrication Processes and Procedures Production Control

Figure 6-5. Significant Manufacturing/ Management Factors Interactions Matrix

SECTION 7

REFERENCES

1. Study of Technology Requirements for Structures of Large Launch Vehicles, 3 Volumes, NASA CR 73343, General Electric Company, 1 July 1969.

2. Building Construction Cost Data, Robert Snow Means Company, Inc., 1969.

3. Manufacturing Plan, Saturn-IVB System, Douglas Report SM-43989, McDonnell Douglas Astronautic Company, 1 March 1964.

4. Presentation—Study of Aerospace Structural Manufacturing Concepts, S-IVB Stage to OART and General Electric, McDonnell Douglas Astronautic Company, 27 May 1967.

5. Manufacturing Plan for Saturn S-II Stage, SID 61-365, Space Division, North American Rockwell Corporation, Reissued 1 June 1969.

6. Presentation—Visit by NASA/Ames and General Electric, Seal Beach, California, Space Division, North American Rockwell Corporation, 26 May 1970.

7. Study of Structural Weight Sensitivities for Large Rocket Systems, 2 Volumes, NASA CR 73087, General Electric Company, July 1967.

8. Study of Aerospace Structural Manufacturing Concepts, Phase I Report, Survey of Manufacturing Techniques and Factors, General Electric Company, Apollo Systems, Contract NAS2-5857, 18 September 1970.

9. Evans, R. M., et al, The Development of a Technique for Improving Rocket Motor Designs Through Production Cost Analysis, Batelle Memorial Institute for U.S. Army Redstone Arsenal, August 1967.

10. Review and Evaluation of Recent Structural Development Programs, NASA MSFC R-ME-IT-10044, 15 August 1966.

11. Mark XII Manufacturing Planning Data, Unpublished. (Selected pages of this material is included in Reference 8 above.)

12. General Purpose Simulation, GPS, General Electric Company, Information Services Department, March 1970.

13. Anon, Statistical and Mathematical Programs, General Electric MARK II Time-Sharing Bulletin 807232A, March 1969.

14. G.E.P. Box and J. S. Hunter, The 2^{K-P} Fractional Factorial Designs, Published by Mathematics Research Center, U.S. Army, Madison, Wisconsin, Under Contract DA-11-022-ORD-2059.

15. A. Hald, Statistical Theory With Engineering Applications; Page 513, John Wiley and Sons, 1962.

APPENDIX A

MANUFACTURING COST ANALYSIS (MANCAN)

PROGRAM LISTING

APPENDIX A

INTRODUCTION

The "MANCAN" Program is written in BASIC language for the MARK II General Electric timesharing computer system. Techniques for use and explanation of language of this program are described in the following manuals, copies of which are available through the General Electric Timesharing Service Offices.

Manual 711223D—"MARK II Command System", Reference Manual published by General Electric Company, Information Services Department, revised May 1970.

Manual 711224A—"MARK II BASIC Language", Reference Manual published by General Electric Company, Information Services Department, dated March 1970.

The program is written to be user-interactive. The user can access and run the program with only a knowledge (as described in Section 3 of this report) of terminal operations.

The following pages provide a listing of the "MANCAN" Program.

Appendix A

Manufacturing Cost Analysis (MANCAN) Program Listing

```
100 FILES *;*;*;*
110 DIM A$(139),B(4),C(33,17)
120 DIM A(130),D(130)
130 DIM G(11,2),E(11),Z(17)
135 DIM X(17)
140 LET L4=L5=L6=15/1000
190 PRINT"DO YOU WANT TO RUN USING FILE INPUT? TYPE YES OR NO.";
200 INPUT X$
210 IF X$="YES" THEN 560
212 PRINT "DO YOU WANT THE OUTPUT IN '$' OR '% OF TOTAL COST'?";
213 PRINT "TYPE $ OR %.";
214 INPUT Y$
230 PRINT "DO YOU DESIRE USER INSTRUCTIONS? TYPE YES OR NO.";
250 INPUT D$
260 IF D$="NO" THEN 600
270 PRINT "     THERE ARE FIVE FACTORS WHICH MUST BE INPUT WHEN THE"
280 PRINT "NEXT QUESTION MARK APPEARS.  THESE MUST BE INPUT IN THE"
290 PRINT "FOLLOWING ORDER:  K1,K2,K3,K4,K5"
300 PRINT "WHERE:"
310 PRINT
320 PRINT "   K1= LINE NUMBER (1,2,OR 3)"
330 PRINT TAB(5);"K1=1: STATE-OF-THE-ART MANUFACTURING LINE"
340 PRINT TAB(5);"K1=2: IMPROVED MANUFACTURING LINE "
350 PRINT TAB(5);"K1=3: ADVANCED MANUFACTURING LINE "
360 PRINT "   K2 ALLOWS THE PRODUCTION RATE SELECTION"
370 PRINT "    (K2=1 FOR 2/YR, K2=2 FOR 20/YR)"
380 PRINT "   K3 ALLOWS THE SELECTION OF THE STRUCTURE"
390 PRINT "    K3=1 FOR THE TANK ASSEMBLY"
400 PRINT "    K3=2 FOR THE MARK XII ADAPTER ASSEMBLY"
410 PRINT"   K4 ALLOWS THE SELECTION OF A CHANGE TO BE MADE TO THE NOMIN
420 PRINT"   MANUFACTURING LINE"
430 PRINT "      K4=1: FOR THE NOMINAL LINE"
440 PRINT "      K4=2: ANY COMBINATION OF THE FOLLOWING CHANGES"
450 PRINT "      K4=3: TOLERANCES ARE RELAXED BY 100%"
460 PRINT "      K4=4: DESIGN CHANGES REDUCED BY 20%"
470 PRINT "      K4=5: PRODUCIBILITY FILE ENLARGED BY 50%"
480 PRINT "      K4=6: ISSUE JOINT ENGR/MFG/QC SPECS"
490 PRINT "      K4=7: IMPROVED SHOP SCHEDULE & LOAD"
500 PRINT "      K4=8: REDUCE QUALITY REQ'MTS BY 20%"
510 PRINT "      K4=9: DECREASE PRE-MFG. LABOR RECYCLE TO 12%"
515 PRINT "        NOTE: 40% LABOR RECYCLE CONSIDERED NOMINAL"
520 PRINT "      K4=10: REDUCE DESIGN COMPLEXITY BY 20%"
522 PRINT "      K4=11: CONSOLIDATE TO 1 FACILITY"
524 PRINT "      K4=12: GO FROM MANNED TO UNMANNED"
526 PRINT "      K4=13: INCREASE PRODUCT SIZE & WT. BY 20%"
528 PRINT "      K4=14: TRAIN 50% OF WORK FORCE"
530 PRINT "      K4=15: GO FROM UNCLASS. TO CLASSIFIED SECURITY"
532 PRINT "      K4=16: MOVE MFG. PLANT FROM FLA. TO OHIO"
540 PRINT "      K4=17: DELETE PLANT SAFETY PROGRAM"
542 PRINT "      K4=18: 5 YR ST. LINE DEPRECIATION"
```

```
544 PRINT "      K4=19: SUM OF YRS DIGIT DEPREC."
546 PRINT "      K4=20: INCR. SHOP LOAD 10% FOR CORRECTIONS"
550 PRINT "   K5 IS THE TOTAL PROGRAM LENGTH IN YEARS"
555 GO TO 600
560 FILE #4,"INPUT"
570 READ #4,K1,K2,K3,K4,K5,P$,K6$,P,Y$
580 IF END #4 THEN 7000
590 GO TO 645
600 INPUT K1,K2,K3,K4,K5
610 IF D$="NO" THEN 640
620 PRINT"DO YOU WANT DETAILED OUTPUT(ENTER D),OR SUMMARY(ENTER S)";
640 INPUT P$
645 LET Q$=P$
650 IF K1>3 THEN 920
660 IF K1=2 THEN 700
670 IF K1=3 THEN 720
680 LET K1$="STATE-OF-THE-ART MANUFACTURING LINE (LINE 1)"
690 GO TO 730
700 LET K1$="IMPROVED MANUFACTURING LINE (LINE 2)"
710 GO TO 730
720 LET K1$="ADVANCED MANUFACTURING LINE (LINE 3)"
730 IF K2=1 THEN 860
740 LET K6=20
750 IF X$="YES" THEN 800
760 IF D$="NO" THEN 790
770 PRINT"DO YOU WANT A LEARNING CURVE EFFECT INCLUDED? YES OR NO";
790 INPUT K6$
800 IF K6$= "NO" THEN 870
810 IF X$="YES" THEN870
820 IF D$="NO" THEN 840
830 PRINT "ENTER THE PERCENT STANFORD CURVE DESIRED ";
840 INPUT P
850 GO TO 870
860 LET K6=2
870 IF K3=1 THEN 900
880 LET K3$="SUPPORT FRUSTUM STRUCTURE (ELEMENT 1)"
890 GO TO 932
900 LET K3$="PROPELLANT TANK STRUCTURE (ELEMENT 2)"
910 GO TO 932
920 PRINT "SORRY, NOT AVAILABLE YET"
930 GO TO 7000
932 IF K4<>2 THEN 960
934 IF X$="YES" THEN 942
936 PRINT "ENTER THE TOTAL NO. OF CHANGES";
938 INPUT Z1
940 GO TO 946
942 READ #4,Z1
944 GO TO 948
946 PRINT "ENTER THE";Z1;"CHANGE NUMBERS";
948 MAT Z =ZER(Z1)
```

```
950 IF X$="YES" THEN 956
952 MAT INPUT Z
954 GO TO 960
956 MAT READ #4,Z
960 PRINT
962 PRINT
964 PRINT
970 PRINT TAB(22);"MANUFACTURING COST ANALYSIS"
980 PRINT TAB(22);    "***************************"
990 PRINT
1000 PRINT
1010 PRINT
1020 PRINT "LINE:  ";K1$
1030 PRINT
1040 PRINT "STRUCTURE:  ";K3$
1050 PRINT
1060 IF K2=1 THEN 1090
1070 LET K2$="20 PER YEAR"
1080 GO TO 1100
1090 LET K2$="2 PER YEAR"
1100 PRINT "PRODUCTION RATE:  ";K2$
1110 IF K2=1 THEN 1141
1120 IF K6$="NO" THEN 1141
1130 PRINT
1140 PRINT "PERCENT LEARNING CURVE USED:";P
1141 PRINT
1160 IF K4>1 THEN 1192
1170 PRINT"VARIATION FROM THE NOMINAL:  NONE"
1180 GO TO 1400
1192 PRINT "VARIATION FROM THE NOMINAL:  CHANGE NO.(S) ";
1193 IF K4<>2 THEN 1208
1194 FOR I=1 TO Z1
1196 PRINT Z(I);
1198 IF I=Z1 THEN 1204
1200 PRINT"+";
1202 NEXT I
1204 PRINT"."
1206 GO TO 1400
1208 PRINT K4
1210 GO TO 1400
1400 PRINT
1410 PRINT"TOTAL PROGRAM LENGTH:";K5;"YEARS; NO. OF UNITS PRODUCED:";K5*
1420 PRINT
1424 PRINT"LABOR RATES-($/HR): PRE-MFG.-";1000*L4;";  Q.C.-";
1425 PRINT 1000*L5;";  MFG.-";1000*L6
1426 PRINT
1430 FILE #3,"FACTORS"
1435 MAT READ #3,C
1436 IF K4<>2 THEN 1445
1438 FOR J=1 TO 17
```

```
1439 FOR I=1 TO Z1
1440 LET C(2,J)=C(2,J)*C(Z(I),J)
1441 NEXT I
1442 NEXT J
1445 IF Y$<>"S" THEN 1450
1448 LET P$="S"
1450 IF P$="S" THEN 1485
1460 PRINT "                              DETAILED CALCULATIONS"
1470 PRINT "                              ====================="
1480 PRINT
1485 IF K3=2 THEN 1582
1490 IF K1=2 THEN 1560
1500 IF K1=3 THEN 1580
1510 IF P$="S" THEN 1540
1520 PRINT TAB(30);"PLANT NO. 1"
1530 PRINT
1540 FILE #1,"LINE1"
1550 GO TO 1590
1560 FILE #1,"LINE2"
1570 GO TO 1590
1580 FILE #1,"LINE3"
1581 GO TO 1590
1582 IF K1=2 THEN 1586
1583 IF K1=3 THEN 1588
1584 FILE #1,"LINE4"
1585 GO TO 1590
1586 FILE #1,"LINE5"
1587 GO TO 1590
1588 FILE #1,"LINE6"
1590 FOR I=1 TO 8
1600 READ #1,A$(I)
1610 NEXT I
1620 IF P$="S" THEN 1665
1630 PRINT TAB(54);A$(1);TAB(60);A$(2);TAB(65);A$(3)
1640 PRINT A$(4);TAB(54);A$(5);TAB(59);A$(6);TAB(65);A$(7)
1650 PRINT"=======";TAB(54);A$(8);TAB(66);A$(8)
1660 PRINT
1665 IF K3=2 THEN 1732
1670 IF K1=2 THEN 1710
1680 IF K1=3 THEN 1730
1690 FILE #2,"DATA1"
1700 GO TO 1750
1710 FILE #2,"DATA2"
1720 GO TO 1750
1730 FILE #2,"DATA3"
1731 GO TO 1750
1732 IF K1=2 THEN 1736
1733 IF K1=3 THEN 1738
1734 FILE #2,"DATA4"
1735 GO TO 1750
```

```
1736 FILE #2,"DATA5"
1737 GO TO 1750
1738 FILE #2,"DATA6"
1750 FOR N=9 TO 140
1760 READ #1,A$(N)
1770 IF END #1 THEN 1960
1785 READ #2,B(1),B(2),B(3),B(4)
1788 IF B(K2)=0 THEN 1950
1790 LET C1=C(K4,B(4))*B(3)*B(K2)
1800 IF P$="S" THEN 1830
1810 PRINT A$(N);TAB(54);B(3);TAB(61);B(K2);TAB(65);C1
1815 IF K3=2 THEN 1840
1820 IF K1>1 THEN 1840
1830 IF N>83 THEN 1940
1840 LET S1=S1+C1
1845 IF K3=2 THEN 1950
1850 IF K1>1 THEN 1950
1860 IF N<>83 THEN 1950
1870 IF P$="S" THEN 1930
1880 PRINT
1890 PRINT TAB(30);"PLANT 1 TOOLING COST (K$)";TAB(64);S1
1900 PRINT
1910 PRINT TAB(30);"PLANT NO.2"
1920 PRINT
1930 IF N=83 THEN 1950
1940 LET S2=S2+C1
1950 NEXT N
1960 IF P$="S" THEN 2050
1965 IF K3=2 THEN 1980
1970 IF K1=1 THEN 2000
1980 LET S2=0
1990 GO TO 2020
2000 PRINT
2010 PRINT TAB(30);"PLANT 2 TOOLING COST (K$)";TAB(64);S2
2020 PRINT TAB(30);"TOTAL TOOLING COST (K$)";TAB(64);S1+S2
2030 PRINT
2040 PRINT
2050 LET L0=K5*K6
2055 IF K3=2 THEN 2114
2060 IF K1>1 THEN 2100
2070 FILE #1,"FACIL1"
2080 READ #1,C3,C4,C5,C6,C7,C8,C9,D1
2090 GO TO 2120
2100 FILE #1,"FACIL2"
2110 READ #1,C3,C4
2111 GO TO 2120
2114 FILE #1,"FACIL3"
2116 READ #1,C3
2120 IF P$="S" THEN 2165
2130 PRINT
```

Appendix A

Manufacturing Cost Analysis (MANCAN) Program Listing (Cont.)

```
2140 PRINT"FACILITIES";TAB(60);"TOTAL COST"
2150 PRINT "==========";TAB(63);"(K$)"
2160 PRINT
2165 IF K3=2 THEN2190
2170 IF K1=1 THEN 2290
2180 IF K2=2 THEN 2230
2190 LET S8=C3*C(K4,14)
2200 LET S2=0
2210 LET T5=0
2220 GO TO 2260
2230 LET S8=C4*C(K4,14)
2240 LET S2=0
2250 LET T5=0
2260 IF P$="S" THEN 2640
2270 PRINT"500 CONSOLIDATED MANUFACTURING & ASSEMBLY PLANT";TAB(63);S8
2280 GO TO 2540
2290 IF K2=1 THEN 2350
2300 LET T4=C9*C(K4,13)
2310 LETT5=L0*D1*C(K4,13)
2320 LET S8=C4*C(K4,14)
2330 LET S9=C6*C(K4,14)
2340 GO TO 2390
2350 LET S8=C3*C(K4,14)
2360 LET S9=C5*C(K4,14)
2370 LET T4=C7*C(K4,13)
2380 LET T5=L0*C8*C(K4,13)
2390 IF P$="S" THEN 2640
2400 PRINT"500 PLANT #1-MANUFACTURING";TAB(63);S8
2410 PRINT"600 PLANT #2-ASSEMBLY";TAB(63);S9
2420 PRINT TAB(61);"---------"
2430 PRINT TAB(63);S8+S9
2440 PRINT
2450 PRINT
2460 PRINT"TRANSPORTATION"
2470 PRINT"=============="
2480 PRINT
2490 PRINT"700 TRANSPORT 100 MILES FROM PLANT 1 TO PLANT 2"
2500 PRINT"701 NON-RECURRING COST";TAB(63);T4
2510 PRINT"702 RECURRING COST";TAB(63);T5
2520 PRINT TAB(61);"---------"
2530 PRINT TAB(63);T4+T5
2540 PRINT
2550 PRINT
2560 PRINT"NEAR-TERM PRE-MANUFACTURING OPERATIONS"
2570 PRINT"======================================"
2580 PRINT
2590 PRINT TAB(25);"NON-RECURRING COSTS"
2600 PRINT TAB(25);"-------------------"
2610 PRINT
2620 PRINT TAB(10);"ITEM";TAB(50);"M/HRS";TAB(60);"TOTAL COST"
```

Manufacturing Cost Analysis (MANCAN) Program Listing (Cont.)

```
2630 PRINT TAB(63);"(K$)"
2640 FILE #1,"L1PREM"
2650 FILE #2,"D1PREM"
2660 MAT READ #2,G
2670 FOR N=1TO 11
2680 READ #1,A$(N)
2690 IF N<>10 THEN 2770
2700 IF P$="S" THEN 2770
2710 PRINT TAB(50);"---------";TAB(60);"-----------"
2720 PRINT TAB(27);"NON-RECURRING TOTALS";TAB(49);S6;TAB(61);S5
2730 PRINT
2740 PRINT TAB(30);"RECURRING COSTS"
2750 PRINT TAB(30);"---------------"
2760 PRINT
2770 IF N>9 THEN  2800
2780 LET L3=L4
2785 IF K3=2 THEN 2895
2790 GO TO 2890
2800 LET L3=L4*L0
2802 IF K3=2 THEN 2816
2810 IF K2=1 THEN 2890
2814 GO TO 2820
2816 IF K2=1 THEN 2895
2820 IF K6$="NO" THEN 2870
2830 LET S=LOG(P/100)/.6931
2835 LET E2=0
2840 FOR I=1 TO INT((20*K5)*10+.5)/10
2845 LET E1=(I)**S
2846 LET E2=E2+E1
2850 NEXT I
2852 LET F=(E2)/(20*K5)
2860 GO TO 2880
2870 LET F=1
2880 LET L3=F*L3
2885 IF K3=2 THEN 2895
2890 LET E(N)=G(N,2)*C(K4,17)*L3
2892 GO TO 2900
2895 LET E(N)=G(N,1)*C(K4,17)*L3
2900 IF P$="S" THEN 2920
2910 PRINT A$(N);TAB(49);E(N)/L4;TAB(61);E(N)
2920 IF N>9 THEN 2960
2930 LET S5=S5+E(N)
2940 LET S6=S5/L4
2950 GO TO 2980
2960 LET S7=S7+E(N)
2970 LET U6=S7/L4
2980 NEXT N
2990 IF P$="S" THEN 3065
3000 PRINT TAB(50);"---------";TAB(60);"-----------"
3010 PRINT TAB(29);"RECURRING TOTALS";TAB(49);U6;TAB(61);S7
```

Appendix A

Manufacturing Cost Analysis (MANCAN) Program Listing (Cont.)

```
3020 PRINT
3030 PRINT TAB(10);"TOTAL RECURRING AND NON-RECURRING PRE-MFG. COSTS=";
3040 PRINT TAB(62);S5+S7
3050 PRINT
3060 PRINT
3065 IF K3=2 THEN 3162
3070 IF K1=2 THEN 3110
3080 IF K1=3 THEN 3130
3090 FILE #1,"LINE1P"
3100 GO TO 3185
3110 FILE#1,"LINE2P"
3120 GO TO 3185
3130 IF K2=2 THEN 3160
3140 FILE #1,"LINE2P"
3150 GO TO 3185
3160 FILE #1,"LIN3AP"
3161 GO TO 3185
3162 IF K1=2 THEN 3171
3163 IF K1=3 THEN 3178
3164 IF K2=2 THEN 3168
3165 FILE #1,"LINE4P"
3166 FILE #2,"DATA4P"
3167 GO TO 3185
3168 FILE #1,"LIN4AP"
3169 FILE #2,"DAT4AP"
3170 GO TO 3185
3171 IF K2=2 THEN 3175
3172 FILE #1,"LINE5P"
3173 FILE #2,"DATA5P"
3174 GO TO 3185
3175 FILE #1,"LIN5AP"
3176 FILE #2,"DAT5AP"
3177 GO TO 3185
3178 FILE #1,"LINE6P"
3179 IF K2=2 THEN 3183
3181 FILE #2,"DATA6P"
3182 GO TO 3185
3183 FILE #2,"DAT6AP"
3185 DELIMIT #1,(LF)
3186 IF K3=2 THEN 3570
3188 IF K1>1 THEN 3570
3190 FOR I=1TO12
3200 READ #1,A$(I)
3210 NEXT I
3220 IF P$="S" THEN 3310
3230 PRINT TAB(35);A$(1);TAB(44);A$(2);TAB(53);A$(3);TAB(58);
3240 PRINT A$(4);TAB(65);A$(5)
3250 PRINT A$(6);TAB(35);A$(7);TAB(43);A$(8);TAB(52);A$(8);
3260 PRINT TAB(59);A$(9);TAB(66);A$(7)
3270 PRINT"======================";TAB(35);A$(10);TAB(43);A$(11);
```

```
3280 PRINT TAB(52);A$(11);TAB(66);A$(10)
3290 PRINT
3300 PRINT A$(12)
3310 FILE #2,"DATA1P"
3350 FOR N=13 TO 124
3360 LET L0=K5*K6
3370 LET L1=L5*L0
3380 LET L2=L6*L0
3390 READ #1,A$(N)
3395 READ #2,D(1),D(2),D(3),D(4),D(5),D(6),D(7)
3400 IF N=23 THEN 3520
3410 IF N=27 THEN 3520
3420 IF N=41 THEN 3520
3430 IF N=48 THEN 3520
3440 IF N=61 THEN 3520
3450 IF N=68 THEN 3520
3460 IF N=81 THEN 3520
3470 IF N=88 THEN 3520
3480 IF N=103 THEN 3520
3490 IF N=111 THEN 3520
3500 LET M=N-12-L
3510 GO TO 3990
3520 LET L=L+1
3522 FOR I=1TO 7
3524 BACKSPACE #2
3526 NEXT I
3530 IF P$="S" THEN 3560
3540 PRINT
3550 PRINT A$(N)
3560 GO TO 4380
3570 FOR I=1TO 11
3580 READ #1,A$(I)
3590 NEXT I
3600 IF P$="S" THEN 3665
3610 PRINT TAB(39);A$(1);TAB(46);A$(2);TAB(53);A$(3);TAB(61);A$(4)
3620 PRINT A$(5);TAB(39);A$(6);TAB(45);A$(7);TAB(52);A$(7);TAB(62);A$(6)
3630 PRINT A$(8);TAB(39);A$(9);TAB(45);A$(10);TAB(52);A$(10);TAB(62);
3640 PRINT A$(9)
3650 PRINT
3660 PRINT A$(11)
3665 IF K3=2 THEN 3764
3670 IF K1=3 THEN 3700
3680 FILE #2,"DATA2P"
3690 GO TO 3764
3700 IF K2=2 THEN 3730
3710 FILE #2,"DATA3P"
3720 GO TO 3764
3730 FILE #2,"DAT3AP"
3764 IF K3=2 THEN 3772
3770 FOR N=12 TO 139
```

```
3771 GO TO 3780
3772 IF K1=2 THEN 3776
3773 IF K1=3 THEN 3778
3774 FOR N=12 TO 46
3775 GO TO 3780
3776 FOR N=12 TO 47
3777 GO TO 3780
3778 FOR N=12 TO 30
3780 LET L0=K5*K6
3790 LET L1=L5*L0
3800 LET L2=L6*L0
3810 READ #1,A$(N)
3811 READ #2,D(1),D(2),D(3),D(4),D(5),D(6)
3812 IF K3=1 THEN 3820
3814 GO TO 6200
3820 IF N=22 THEN 3930
3830 IF N=26 THEN 3930
3840 IF N=45 THEN 3930
3850 IF N=52 THEN 3930
3860 IF N=69 THEN 3930
3870 IF N=76 THEN 3930
3880 IF N=93 THEN 3930
3890 IF N=100 THEN 3930
3900 IF N=113 THEN 3930
3910 IF N=121 THEN 3930
3920 GO TO 3980
3930 LET L=L+1
3932 FOR I=1 TO 6
3934 BACKSPACE #2
3936 NEXT I
3940 IF P$="S" THEN 4300
3950 PRINT
3960 PRINT A$(N)
3970 GO TO 4300
3980 LET M=N-11-L
3990 IF K2=1 THEN 4080
4000 IF K6$= "NO" THEN 4050
4010 LET S=LOG(P/100)/.6931
4020 LET F=F
4030 LET F=F
4040 GO TO 4060
4050 LET F=1
4060 LET L1=F*L1
4070 LET L2=F*L2
4080 LET T1=L0*D(1)*C(K4,D(2))
4100 LET T2=L1*D(3)*C(K4,D(4))
4120 LET T3=L2*D(5)*C(K4,D(6))
4140 LET A(M)=INT((T1+T2+T3)*1000+.5)/1000
4141 LET T6=INT((T2/L5)*1000+.5)/1000
4142 LET T7=INT((T3/L6)*1000+.5)/1000
```

Manufacturing Cost Analysis (MANCAN) Program Listing (Cont.)

```
4150 IF P$="S" THEN 4230
4160 PRINT A$(N);
4165 IF K3=2 THEN 4210
4170 IF K1>1 THEN 4210
4180 PRINT TAB(35);T1;TAB(41);T6;TAB(50);T7;TAB(60);
4190 PRINT D(7);TAB(64);A(M)
4200 GO TO 4240
4210 PRINT TAB(39);T1;TAB(46);T6;TAB(53);T7;TAB(61);A(M)
4220 GO TO 4250
4230 IF K1>1 THEN 4250
4235 IF K3=2 THEN 4250
4240 IF D(7)=2 THEN 4310
4250 LET S3=S3+A(M)
4260 LET M1=M1+T1
4270 LET Q1=Q1+T6
4280 LET Q3=Q3+T7
4285 IF K3=2 THEN 4300
4290 IF K1=1 THEN 4380
4300 IF K3=2 THEN 4302
4301 GO TO 4360
4302 IF K1=2 THEN 4354
4303 IF K1=3 THEN 4352
4304 GO TO 4356
4310 LET S4=S4+A(M)
4320 LET M2=M2+T1
4330 LET Q2=Q2+T6
4340 LET Q4=Q4+T7
4350 GO TO 4380
4352 NEXT N
4353 GO TO 4390
4354 NEXT N
4355 GO TO 4390
4356 NEXT N
4357 GO TO 4390
4360 NEXT N
4370 GO TO 4390
4380 NEXT N
4390 IF K1=1 THEN 4430
4400 LET S4=0
4410 LET Q2=0
4420 LET Q4=0
4430 LET T=S1+S2+S3+S4+S5+S7+T4+T5+S8+S9
4431 LET Q5=INT(Q1*L5*1000+.5)/1000
4432 LET Q6=INT(Q3*L6*1000+.5)/1000
4433 LET Q7=INT(Q2*L5*1000+.5)/1000
4434 LET Q8=INT(Q4*L6*1000+.5)/1000
4435 IF Y$<>"X" THEN 4440
4436 PRINT
4437 PRINT TAB(20);"TOTAL PROGRAM COST 'T'=";T*1000;"DOLLARS"
4438 PRINT
```

Manufacturing Cost Analysis (MANCAN) Program Listing (Cont.)

```
4439 GO SUB 5310
4440 IF P$="S" THEN 4600
4445 IF K3=2 THEN 4460
4450 IF K1=1 THEN 4490
4460 PRINT TAB(38);"-------- ------ ------ ----------"
4470 PRINT TAB(39);M1;TAB(47);Q1;TAB(54);Q3;TAB(62);S3+S4
4474 PRINT TAB(20);"LABOR COST (K$)";TAB(43);"(";Q5;
4475 PRINT ")";TAB(55);"(";Q6;")"
4480 GO TO 4600
4490 PRINT
4500 PRINT TAB(43);"PLANT 1";TAB(53);"PLANT 2";TAB(65);"TOTAL"
4510 PRINT TAB(43);"-------";TAB(53);"-------";TAB(65);"-----"
4520 PRINT"MANUFACTURING PROCESSES";K5;"YR COST-(K$)";TAB(40);S3;
4530 PRINT TAB(50);S4;TAB(62);S3+S4
4540 PRINT TAB(5);"MATERIAL COST-(K$)";TAB(40);M1;TAB(50);M2;
4550 PRINT TAB(62);M1+M2
4560 PRINT TAB(5);"QUALITY CONTROL LABOR-(M/HRS)";TAB(40);Q1;
4570 PRINT TAB(50);Q2;TAB(62);Q1+Q2
4572 PRINT TAB(27);"-(K$)";TAB(38);Q5;TAB(49);Q7;TAB(62);Q5+Q7
4580 PRINT TAB(5);"MANUFACTURING LABOR-(M/HRS)";TAB(40);Q3;
4590 PRINT TAB(50);Q4;TAB(62);Q3+Q4
4592 PRINT TAB(25);"-(K$)";TAB(38);Q6;TAB(49);Q8;TAB(62);Q6+Q8
4600 PRINT
4610 PRINT
4620 PRINT TAB(25);"SUMMARY OF RESULTS"
4630 PRINT TAB(25);"------------------"
4640 PRINT
4650 PRINT
4660 PRINT TAB(21);"MAT'L";TAB(31);"Q.C.";TAB(41);"MFG.";TAB(49);
4670 PRINT"PRE-MFG.";TAB(61);"TOTAL"
4680 PRINT TAB(21);"COST";TAB(31);"LABOR";TAB(41);
4690 PRINT "LABOR";TAB(51);"LABOR";TAB(61);"COST"
4692 IF Y$="S" THEN 4700
4694 PRINT TAB(21);"(%T)";TAB(30);"(%T)";TAB(40);
4696 PRINT "(%T)";TAB(50);"(%T)";TAB(61);"(%T)"
4698 GO TO 4720
4700 PRINT TAB(21);"(K$)";TAB(30);"(M/HR)";TAB(40);
4710 PRINT "(M/HR)";TAB(50);"(M/HR)";TAB(61);"(K$)"
4720 PRINT
4730 PRINT"TOOLING";TAB(60);S1+S2
4740 PRINT "FACILITIES";TAB(60);S8+S9
4745 IF K3=2 THEN 4790
4750 IF K1>1 THEN 4790
4760 PRINT"TRANSPORTATION"
4770 PRINT"    NON-RECURRING COST";TAB(60);T4
4780 PRINT"    RECURRING COST";TAB(60);T5
4790 PRINT"PRE-MANUFACTURING"
4800 PRINT"    NON-RECURRING COST";TAB(49);S6;TAB(60);S5
4810 PRINT"    RECURRING COST";TAB(49);U6;TAB(60);S7
4820 PRINT"MFG. PROCESSES";TAB(20);M1+M2;TAB(30);Q1+Q2;
```

Appendix A

Manufacturing Cost Analysis (MANCAN) Program Listing (Cont.)

```
4830 PRINT TAB(40);Q3+Q4;TAB(60);S3+S4
4840 PRINT TAB(19);"----------";TAB(29);"----------";TAB(39);
4850 PRINT"----------";TAB(49);"------------";TAB(61);"-----------"
4860 PRINT TAB(20);M1+M2;TAB(30);Q1+Q2;TAB(40);Q3+Q4;TAB(50);
4870 PRINT U6+S6;TAB(60);T
4872 IF Y$="%" THEN 4879
4874 PRINT
4876 PRINT"LABOR IN (K$)";TAB(27);"(";Q5+Q7;")";TAB(39);"(";
4877 PRINT Q6+Q8;")";"  UNIT COST:";T/(K5*K6)
4879 IF K3=2 THEN 5050
4880 IF K1>1 THEN 5050
4890 PRINT
4900 PRINT
5050 FOR I=1 TO 6
5060 PRINT
5070 NEXT I
5072 IF Q$="S" THEN 5080
5073 IF Y$="$" THEN 5080
5074 LET P$=Q$
5076 LET Y$="%%"
5078 GO TO 1460
5080 IF X$="NO" THEN 7000
5090 RESTORE #1
5100 RESTORE#2
5110 RESTORE #3
5120 LET L=S1=S2=S3=S4=S5=S7=T4=T5=S8=S9=M1=M2=Q1=Q2=Q3=Q4=U6=S6=0
5300 GO TO 570
5310 LET S1=S1*100/T
5320 LET S2=S2*100/T
5330 LET S8=S8*100/T
5340 LET S9=S9*100/T
5350 LET T4=T4*100/T
5360 LETT5=T5*100/T
5370 LET U6=U6*L4*100/T
5380 LET S6=S6*L4*100/T
5390 LET S5=S5*100/T
5400 LET S7=S7*100/T
5410 LET M1=M1*100/T
5420 LET M2=M2*100/T
5430 LET Q1=Q1*L5*100/T
5440 LET Q2=Q2*L5*100/T
5450 LET Q3=Q3*L6*100/T
5460 LET Q4=Q4*L6*100/T
5470 LET S3=S3*100/T
5480 LET S4=S4*100/T
5490 LET T=100
5500 RETURN
6000 PRINT"MANUFACTURING PROCESSES";K5;"YR COST-(%T)";TAB(40);S3;
6010 PRINT TAB(50);S4;TAB(62);S3+S4
6020 PRINT TAB(5);"MATERIAL COST-(%T)";TAB(40);M1;TAB(50);M2;
```

```
6030 PRINT TAB(62);M1+M2
6040 PRINT TAB(5);"QUALITY CONTROL LABOR-(%T)";TAB(40);Q1;
6050 PRINT TAB(50);Q2;TAB(62);Q1+Q2
6060 PRINT TAB(5);"MANUFACTURING LABOR-(%T)";TAB(40);Q3;
6070 PRINT TAB(50);Q4;TAB(62);Q3+Q4
6080 PRINT "FACILITIES, MFG. & ASSEMBLY-(%T)";TAB(40);S8;
6090 PRINT TAB(50);S9;TAB(62);S8+S9
6100 PRINT "TOOLING-(%T)";TAB(40);S1;TAB(50);S2;TAB(62);S1+S2
6110 PRINT"TRANSPORTATION-(%T)";TAB(41);"FROM          TO";TAB(62);T4+T5
6115 RETURN
6200 IF K1=2 THEN 6260
6210 IF K1=3 THEN 6300
6220 IF N=22 THEN 3930
6230 IF N=29 THEN 3930
6240 IF N=36 THEN 3930
6250 GO TO 3960
6260 IF N=23 THEN 3930
6270 IF N=30 THEN 3930
6280 IF N=39 THEN 3930
6290 GO TO 3960
6300 IF N=17 THEN 3930
6310 IF N=22 THEN 3930
6320 GO TO 3960
7000 END
```

APPENDIX B

LISTING OF COMPUTER OUTPUTS (BY RUN NUMBER) USED IN DETERMINING THE IMPACT OF CHANGES TO FACTORS ON MANUFACTURING COST

APPENDIX B

INTRODUCTION

This Appendix provides a detailed tabulation of the results of the significant computer runs from this study. References to changes in the manufacturing processes are made by number and refer to those changes tabulated in Figure B-1. Cost groups are noted in Figure B-2.

Change Number	Change Description
3	Relaxed Tolerances by 100%
4	Reduce Number of Design Changes by 20%
5	Enlarge Producibility Information File by 50%
6	Issue Joint Engineering/Manufacturing Quality Control Specifications
7	Improve Shop Schedule and Load—15% Less Changes
8	Reduce Quality Required by 20%
9	Decrease Pre-Manufacturing Labor Recycle From 40 to 12%
10	Reduce Design Complexity by 20%
11	Consolidate Facilities—One Factory
12	Manned to Unmanned
13	Increase Product Size and Weight 20%
14	Train 50% of Work Force
15	Security—Nonclassified to Classified
16	Site Selection—Labor Cost Florida to Ohio
17	Delete Plant Safety
18	Depreciation—Straight-Line F-1 to "0" in 40 Years F-2 to "0" in 14 Years T-1 + T-2 to "0" at End of Program
19	Depreciation—Sum of Digits F-1 to "0" in 40 Years F-2 to "0" in 14 Years T-1 + T-2 to "0" at End of Program
20	Increase Shop Load 10% for Discrepancy Corrections

Figure B-1. Change Identification

Cost Group		Cost Group Title
Number	Designation	
1	M 1	Raw Material
2	M 2	In-Process Material
3	I 1	Inspect—Form, Dimension
4	I 2	Inspect—Weld, Bond
5	I 3	Inspect—Assemble, Other
6	S 1	Machining
7	S 2	Forming
8	S 3	Joining
9	T 1	Tooling, Material, Handling
10	T 2	Jigs and Fixtures
11	A 1	Test—Accept
12	D 1	Storage
13	D 2	Transport
14	F 1	Facilities—Buildings
15	F 2	Furnaces and Machine Tools
16	P 1	Processing—Chem Mill, Anneal, Cure
17	L 1	Pre-Manufacturing Labor

Figure B-2. Cost Group Identification

Table B-1

Listing of Computer Outputs

N = Not Incorporated
Y = Incorporated

Detail Run Number	Program Cost, K$	Element Unit Cost, K$	Element Number	Line Number	Production Rate Capability/Year	Quantity Produced	Depreciation Method	Learning Curve, %	Property Tax, $30/1000	Interest on Capital, 6%	Program Length-Years - Basis for Taxes, Interest and Depreciation as Appropriate	NOTE: (See Figures 1 and 2 for Change Identification)
1D	1094.0	109.4	1	1	2	10	100%	100	N	N	5	Baseline Run
2D	2183.7	21.8	1	1	20	100	100%	100	N	N	5	Baseline Run
3D	1165.0	116.5	1	2	2	10	100%	100	N	N	5	Baseline Run
4D	2112.8	21.1	1	2	20	100	100%	100	N	N	5	Baseline Run
5D	1261.1	126.1	1	3	2	10	100%	100	N	N	5	Baseline Run
6D	1974.7	19.7	1	3	20	100	100%	100	N	N	5	Baseline Run
7D	17576.1	1757.6	2	1	2	10	100%	100	N	N	5	Baseline Run
8D	67387.7	673.9	2	1	20	100	100%	100	N	N	5	Baseline Run
9D	14538.4	1453.8	2	2	2	10	100%	100	N	N	5	Baseline Run
10D	60183.1	601.8	2	2	20	100	100%	100	N	N	5	Baseline Run
11D	17132.3	1713.2	2	3	2	10	100%	100	N	N	5	Baseline Run
12D	58079.6	580.8	2	3	20	100	100%	100	N	N	5	Baseline Run

N = Not Incorporated
Y = Incorporated

Table B-1
Listing of Computer Outputs (Cont.)

Summary Run Number	Program Cost, K$	Element Unit Cost, K$	Element Number	Line Number	Production Rate Capability/Year	Quantity Produced	Depreciation Method	Learning Curve, %	Property Tax, $30/1000	Interest on Capital, 6%	Program Length-Years - Basis for Taxes, Interest and Depreciation as Appropriate	NOTES
1	33709.9	33709.9	2	1	20	1	100%	100	N	N	1	
2	34050.1	17025.0	2	1	20	2	100%	100	N	N	1	
3	34730.4	8682.6	2	1	20	4	100%	100	N	N	1	
4	36771.5	3677.2	2	1	20	10	100%	100	N	N	1	
5	40173.3	2008.7	2	1	20	20	100%	100	N	N	1	
6	53780.5	896.3	2	1	20	60	100%	100	N	N	3	
7	67387.7	673.9	2	1	20	100	100%	100	N	N	5	Baseline Run - See Run 8D
8	101406.0	507.0	2	1	20	200	100%	100	N	N	10	
1A	36619.5	36619.5	2	1	20	1	100%	100	Y	Y	1	
4A	43082.9	2154.2	2	1	20	20	100%	100	Y	Y	1	
7A	81935.9	819.4	2	1	20	100	100%	100	Y	Y	5	
9	8571.1	8571.1	2	1	20	1	SL	100	Y	Y	1	
10	8911.3	4455.6	2	1	20	2	SL	100	Y	Y	1	
11	9591.6	2397.9	2	1	20	4	SL	100	Y	Y	1	
12	11632.7	1163.3	2	1	20	10	SL	100	Y	Y	1	
13	15034.5	751.7	2	1	20	20	SL	100	Y	Y	1	
14	36404.0	606.7	2	1	20	60	SL	100	Y	Y	3	
15	57636.1	576.4	2	1	20	100	SL	100	Y	Y	5	
16	110217.0	551.1	2	1	20	200	SL	100	Y	Y	10	
17	8571.1	8571.1	2	1	20	1	SL	80	Y	Y	1	
18	9424.8	2356.2	2	1	20	4	SL	80	Y	Y	1	

Table B-1

Listing of Computer Outputs (Cont.)

N = Not Incorporated
Y = Incorporated

Summary Run Number	Program Cost, K$	Element Unit Cost, K$	Element Number	Line Number	Production Rate Capability/Year	Quantity Produced	Depreciation Method	Learning Curve, %	Property Tax, $30/1000	Interest on Capital, 6%	Program Length-Years - Basis for Taxes, Interest and Depreciation as Appropriate	NOTES
19	13184.1	659.2	2	1	20	20	SL	80	Y	Y	1	
20	44539.0	445.4	2	1	20	100	SL	80	Y	Y	5	
21	3919.1	3919.1	2	1	20	1	SL	80	Y	Y	1	Changes 3 through 12
22	4223.9	1056.0	2	1	20	4	SL	80	Y	Y	1	Changes 3 through 12
23	5608.0	280.4	2	1	20	20	SL	80	Y	Y	1	Changes 3 through 12
24	20237.0	202.4	2	1	20	100	SL	80	Y	Y	5	Changes 3 through 12
25	885.7	885.7	1	1	20	1	100%	100	N	N	1	
29	1134.8	56.7	1	1	20	20	100%	100	N	N	1	
31	2183.7	21.8	1	1	20	100	100%	100	N	N	5	Baseline Run - See Run 2D
25A	951.2	951.2	1	1	20	1	100%	100	Y	Y	1	
29A	1200.3	60.0	1	1	20	20	100%	100	Y	Y	1	
31A	2511.0	25.1	1	1	20	100	100%	100	Y	Y	5	
33	288.8	288.8	1	1	20	1	SL	100	Y	Y	1	
37	538.0	26.9	1	1	20	20	SL	100	Y	Y	1	
39	1922.3	19.2	1	1	20	100	SL	100	Y	Y	5	
41	288.8	288.8	1	1	20	1	SL	80	Y	Y	1	
43	460.5	23.0	1	1	20	20	SL	80	Y	Y	1	
44	1374.0	13.7	1	1	20	100	SL	80	Y	Y	5	
49	63519.0	635.2	2	1	20	100	100%	100	N	N	5	Baseline Run 8D+ Change 3
50	56913.8	569.1	2	1	20	100	100%	100	N	N	5	Baseline Run 8D+ Change 4

Table B-1
Listing of Computer Outputs (Cont.)

N = Not Incorporated
Y = Incorporated

Summary Run Number	Program Cost, K$	Element Unit Cost, K$	Element Number	Line Number	Production Rate Capability/Year	Quantity Produced	Depreciation Method	Learning Curve, %	Property Tax, $30/1000	Interest on Capital, 6%	Program Length-Years - Basis for Taxes, Interest and Depreciation as Appropriate	NOTES
51	60582.8	605.8	2	1	20	100	100%	100	N	N	5	Baseline Run 8D+ Change 5
52	60782.3	607.8	2	1	20	100	100%	100	N	N	5	Baseline Run 8D+ Change 6
53	63815.4	638.2	2	1	20	100	100%	100	N	N	5	Baseline Run 8D+ Change 7
54	59461.2	594.6	2	1	20	100	100%	100	N	N	5	Baseline Run 8D+ Change 8
55	66894.1	668.9	2	1	20	100	100%	100	N	N	5	Baseline Run 8D+ Change 9
56	64301.2	643.0	2	1	20	100	100%	100	N	N	5	Baseline Run 8D+ Change 10
57	58640.5	586.4	2	1	20	100	100%	100	N	N	5	Baseline Run 8D+ Change 11
58	66249.4	662.5	2	1	20	100	100%	100	N	N	5	Baseline Run 8D+ Change 12
59	85952.8	859.5	2	1	20	100	100%	100	N	N	5	Baseline Run 8D+ Change 13
60	83917.1	839.2	2	1	20	100	100%	100	N	N	5	Baseline Run 8D+ Change 14
61	74748.9	747.5	2	1	20	100	100%	100	N	N	5	Baseline Run 8D+ Change 15
62	71954.3	719.5	2	1	20	100	100%	100	N	N	5	Baseline Run 8D+ Change 16
63	65837.2	658.4	2	1	20	100	100%	100	N	N	5	Baseline Run 8D+ Change 17
64	43536.7	435.4	2	1	20	100	SL	100	N	N	5	Baseline Run 8D+ Change 18
65	47128.0	471.3	2	1	20	100	SD	100	N	N	5	Baseline Run 8D+ Change 19
66	69983.6	699.8	2	1	20	100	100%	100	N	N	5	Baseline Run 8D+ Change 20
67	81746.5	817.5	2	1	20	100	100%	100	N	N	5	Baseline Run 8D+ Changes 10 + 13
68	92818.8	928.2	2	1	20	100	100%	100	N	N	5	Baseline Run 8D+ Changes 14 + 16 + 20
69	2045.6	20.5	1	1	20	100	100%	100	N	N	5	Baseline Run 2D+ Change 3
70	1816.7	18.2	1	1	20	100	100%	100	N	N	5	Baseline Run 2D+ Change 4

Table B-1
Listing of Computer Outputs (Cont.)

N = Not Incorporated
Y = Incorporated

Summary Run Number	Program Cost, K$	Element Unit Cost, K$	Element Number	Line Number	Production Rate Capability/Year	Quantity Produced	Depreciation Method	Learning Curve, %	Property Tax, $30/1000	Interest on Capital, 6%	Program Length-Years - Basis for Taxes, Interest and Depreciation as Appropriate	NOTES
71	2024.2	20.2	1	1	20	100	100%	100	N	N	5	Baseline Run 2D + Change 5
72	1972.8	19.7	1	1	20	100	100%	100	N	N	5	Baseline Run 2D + Change 6
73	2057.4	20.6	1	1	20	100	100%	100	N	N	5	Baseline Run 2D + Change 7
74	1862.8	18.6	1	1	20	100	100%	100	N	N	5	Baseline Run 2D + Change 8
75	2055.7	20.6	1	1	20	100	100%	100	N	N	5	Baseline Run 2D + Change 9
76	2118.8	21.2	1	1	20	100	100%	100	N	N	5	Baseline Run 2D + Change 10
	Change	11 Not	Applicable									
	Change	12 Not	Applicable									
79	2853.7	28.5	1	1	20	100	100%	100	N	N	5	Baseline Run 2D + Change 13
80	2889.2	28.9	1	1	20	100	100%	100	N	N	5	Baseline Run 2D + Change 14
81	2532.1	25.3	1	1	20	100	100%	100	N	N	5	Baseline Run 2D + Change 15
82	2307.7	23.1	1	1	20	100	100%	100	N	N	5	Baseline Run 2D + Change 16
83	2162.4	21.6	1	1	20	100	100%	100	N	N	5	Baseline Run 2D + Change 17
84	1604.5	16.0	1	1	20	100	SL	100	N	N	5	Baseline Run 2D + Change 18
85	1679.6	16.8	1	1	20	100	SD	100	N	N	5	Baseline Run 2D + Change 19
86	2290.2	22.9	1	1	20	100	100%	100	N	N	5	Baseline Run 2D + Change 20
89	119.7	119.7	1	1	20	1	SL	80	Y	Y	1	Changes 3 through 10 + 12
91	194.0	9.7	1	1	20	20	SL	80	Y	Y	1	Changes 3 through 10 + 12
92	701.0	7.0	1	1	20	100	SL	80	Y	Y	5	Changes 3 through 10 + 12

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Table B-1
Listing of Computer Outputs (Cont.)

Summary Run Number	Program Cost, K$	Element Unit Cost, K$	Element Number	Line Number	Production Rate Capability/Year	Quantity Produced	Depreciation Method	Learning Curve, %	Property Tax, $30/1000	Interest on Capital, 6%	Program Length-Years - Basis for Taxes, Interest and Depreciation as Appropriate	NOTES
93	15700.9	15700.9	2	1	2	1	100%	100	Y	Y	1	
94	17907.8	4477.0	2	1	2	4	100%	100	Y	Y	2	
95	23508.0	2350.8	2	1	2	10	100%	100	Y	Y	5	
96	3765.9	3765.9	2	1	2	1	SL	100	Y	Y	1	
97	6404.9	1601.2	2	1	2	4	SL	100	Y	Y	2	
98	13229.3	1322.9	2	1	2	10	SL	100	Y	Y	5	
99	1606.3	1606.3	2	1	2	1	SL	100	Y	Y	1	Changes 3 through 12
100	2881.1	720.3	2	1	2	4	SL	100	Y	Y	2	Changes 3 through 12
101	6305.2	630.5	2	1	2	10	SL	100	Y	Y	5	Changes 3 through 12
102	1245.2	1245.2	1	3	20	1	100%	100	Y	Y	1	
103	1402.5	70.1	1	3	20	20	100%	100	Y	Y	1	
104	2425.3	24.3	1	3	20	100	100%	100	Y	Y	5	
105	328.1	328.1	1	3	20	1	SL	100	Y	Y	1	
106	485.4	24.3	1	3	20	20	SL	100	Y	Y	1	
107	1654.1	16.5	1	3	20	100	SL	100	Y	Y	5	
109	429.1	21.5	1	3	20	20	SL	80	Y	Y	1	Use Run 105 Data for Quantity Produced = 1 with 80% Learning Curve
110	1255.6	12.6	1	3	20	100	SL	80	Y	Y	5	
111	149.5	149.5	1	3	20	1	SL	80	Y	Y	1	Changes 3 through 10 + 12
112	190.0	9.5	1	3	20	20	SL	80	Y	Y	1	Changes 3 through 10 + 12

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Table B-1
Listing of Computer Outputs (Cont.)

Summary Run Number	Program Cost, K$	Element Unit Cost, K$	Element Number	Line Number	Production Rate Capability/Year	Quantity Produced	Depreciation Method	Learning Curve, %	Property Tax, $30/1000	Interest on Capital, 6%	Program Length-Years - Basis for Taxes, Interest and Depreciation as Appropriate	NOTES
113	691.8	6.9	1	3	20	100	SL	80	Y	Y	5	Changes 3 through 10 + 12
114	31497.8	31497.9	2	3	20	1	100%	100	Y	Y	1	
115	37078.6	1853.9	2	3	20	20	100%	100	Y	Y	1	
116	70562.4	705.6	2	3	20	100	100%	100	Y	Y	5	
117	7926.0	7926.0	2	3	20	1	SL	100	Y	Y	1	
118	13506.6	675.3	2	3	20	20	SL	100	Y	Y	1	
119	50603.1	506.0	2	3	20	100	SL	100	Y	Y	5	
120	11935.7	596.8	2	3	20	20	SL	80	Y	Y	1	Use Run 117 Data for Quantity Produced = 1 with 80% Learning Curve
121	39484.1	394.8	2	3	20	100	SL	80	Y	Y	5	
122	5709.8	5709.8	2	3	20	1	SL	80	Y	Y	1	Changes 4 + 5 + 8
123	7895.9	394.8	2	3	20	20	SL	80	Y	Y	1	Changes 4 + 5 + 8
124	26171.3	261.7	2	3	20	100	SL	80	Y	Y	5	Changes 4 + 5 + 8
125	4156.2	4156.2	2	3	20	1	SL	80	Y	Y	1	Changes 3 through 10 + 12
126	5748.2	287.4	2	3	20	20	SL	80	Y	Y	1	Changes 3 through 10 + 12
127	21047.5	210.5	2	3	20	100	SL	80	Y	Y	5	Changes 3 through 10 + 12
128	6190.6	6190.6	2	1	20	1	SL	80	Y	Y	1	Changes 4 + 5 + 8
129	8701.1	435.1	2	1	20	20	SL	80	Y	Y	1	Changes 4 + 5 + 8
130	29504.0	295.0	2	1	20	100	SL	80	Y	Y	5	Changes 4 + 5 + 8

Table B-1

Listing of Computer Outputs (Cont.)

N = Not Incorporated
Y = Incorporated

Summary Run Number	Program Cost, K$	Element Unit Cost, K$	Element Number	Line Number	Production Rate Capability/Year	Quantity Produced	Depreciation Method	Learning Curve, %	Property Tax, $30/1000	Interest on Capital, 6%	Program Length-Years - Basis for Taxes, Interest and Depreciation as Appropriate	NOTES
131	209.8	209.8	1	1	20	1	SL	80	Y	Y	1	Changes 4 + 8
132	314.1	15.7	1	1	20	20	SL	80	Y	Y	1	Changes 4 + 8
133	955.9	9.6	1	1	20	100	SL	80	Y	Y	5	Changes 4 + 8
134	246.3	246.3	1	3	20	1	SL	80	Y	Y	1	Changes 4 + 8
135	308.1	15.4	1	3	20	20	SL	80	Y	Y	1	Changes 4 + 8
136	952.2	9.5	1	3	20	100	SL	80	Y	Y	5	Changes 4 + 8
137	987.6	987.6	1	1	2	1	100%	100	Y	Y	1	
138	1113.6	278.4	1	1	2	4	100%	100	Y	Y	2	
139	1433.7	143.4	1	1	2	10	100%	100	Y	Y	5	
140	298.7	298.7	1	1	2	1	SL	100	Y	Y	1	
141	446.0	111.5	1	1	2	4	SL	100	Y	Y	2	
142	826.1	82.6	1	1	2	10	SL	100	Y	Y	5	
143	216.7	216.7	1	1	2	1	SL	100	Y	Y	1	Changes 4 + 8
144	331.3	82.8	1	1	2	4	SL	100	Y	Y	2	Changes 4 + 8
145	636.9	63.7	1	1	2	10	SL	100	Y	Y	5	Changes 4 + 8
146	1248.3	1248.3	1	3	2	1	100%	100	Y	Y	1	
147	1372.8	343.2	1	3	2	4	100%	100	Y	Y	2	
148	1711.8	171.2	1	3	2	10	100%	100	Y	Y	5	

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Table B-1

Listing of Computer Outputs (Cont.)

Summary Run Number	Program Cost, K$	Element Unit Cost, K$	Element Number	Line Number	Production Rate Capability/Year	Quantity Produced	Depreciation Method	Learning Curve, %	Property Tax, $30/1000	Interest on Capital, 6%	Program Length-Years - Basis for Taxes, Interest and Depreciation as Appropriate	NOTES
149	331.3	331.3	1	3	2	1	SL	100	Y	Y	1	
150	493.8	123.4	1	3	2	4	SL	100	Y	Y	2	
151	940.6	94.1	1	3	2	10	SL	100	Y	Y	5	
152	248.2	248.2	1	3	2	1	SL	100	Y	Y	1	Changes 4 + 8
153	383.7	95.9	1	3	2	4	SL	100	Y	Y	2	Changes 4 + 8
154	763.6	76.4	1	3	2	10	SL	100	Y	Y	5	Changes 4 + 8
155	2662.6	2662.6	2	1	2	1	SL	100	Y	Y	1	Changes 4 + 5 + 8
156	4533.9	1133.5	2	1	2	4	SL	100	Y	Y	2	Changes 4 + 5 + 8
157	9517.8	951.8	2	1	2	10	SL	100	Y	Y	5	Changes 4 + 5 + 8
158	15620.5	15620.5	2	3	2	1	100%	100	Y	Y	1	
159	17704.6	4426.2	2	3	2	4	100%	100	Y	Y	2	
160	23057.8	2305.8	2	3	2	10	100%	100	Y	Y	5	
161	3765.8	3765.8	2	3	2	1	SL	100	Y	Y	1	
162	6392.8	1598.2	2	3	2	4	SL	100	Y	Y	2	
163	13280.9	1328.1	2	3	2	10	SL	100	Y	Y	5	
164	2689.2	2689.2	2	3	2	1	SL	100	Y	Y	1	Changes 4 + 5 + 8
165	4585.5	1146.4	2	3	2	4	SL	100	Y	Y	2	Changes 4 + 5 + 8
166	9691.6	969.2	2	3	2	10	SL	100	Y	Y	5	Changes 4 + 5 + 8

N = Not Incorporated
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Table B-1
Listing of Computer Outputs (Cont.)

Summary Run Number	Program Cost, K$	Element Unit Cost, K$	Element Number	Line Number	Production Rate Capability/Year	Quantity Produced	Depreciation Method	Learning Curve, %	Property Tax, $30/1000	Interest on Capital, 6%	Program Length-Years - Basis for Taxes, Interest and Depreciation as Appropriate	NOTES
167	54290.5	542.9	2	1	20	100	100%	80	N	N	5	
168	47838.6	478.4	2	2	20	100	100%	80	N	N	5	
169	46960.5	469.6	2	3	20	100	100%	80	N	N	5	
170	17576.1	1757.6	2	1	2	10	100%	100	N	N	5	Baseline Run - See Run 7D for % Only
171	67387.7	673.9	2	1	20	100	100%	100	N	N	5	Baseline Run - See Run 8D for % Only
172	54296.5	542.9	2	1	20	100	100%	80	N	N	5	See Run 167 for % Only
173	14538.5	1453.9	2	2	2	10	100%	100	N	N	5	Baseline Run - See Run 9D for % Only
174	60183.1	601.8	2	2	20	100	100%	100	N	N	5	Baseline Run - See Run 10D for % Only
175	47838.6	478.4	2	2	20	100	100%	80	N	N	5	See Run 168 for % Only
176	17132.3	1713.2	2	3	2	10	100%	100	N	N	5	Baseline Run - See Run 11D for % Only
177	58079.6	580.8	2	3	20	100	100%	100	N	N	5	Baseline Run - See Run 12D for % Only
178	46960.5	469.6	2	3	20	100	100%	80	N	N	5	See Run 169 for % Only
179	30924.9	30924.9	2	2	20	1	100%	80	Y	Y	1	
180	31728.4	7932.1	2	2	20	4	100%	80	Y	Y	1	
182	33131.8	3313.2	2	2	20	10	100%	80	Y	Y	1	

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Table B-1
Listing of Computer Outputs (Cont.)

Summary Run Number	Program Cost, K$	Element Unit Cost, K$	Element Number	Line Number	Production Rate Capability/Year	Quantity Produced	Depreciation Method	Learning Curve, %	Property Tax, $30/1000	Interest on Capital, 6%	Program Length-Years - Basis for Taxes, Interest and Depreciation as Appropriate	NOTES
183	35265.7	1763.3	2	2	20	20	100%	80	Y	Y	1	
184	60073.9	600.7	2	2	20	100	100%	80	Y	Y	5	
185	30924.9	30924.9	2	2	20	1	100%	100	Y	Y	1	
186	31885.7	7971.4	2	2	20	4	100%	100	Y	Y	1	
187	33807.2	3380.7	2	2	20	10	100%	100	Y	Y	1	
188	37009.8	1850.9	2	2	20	20	100%	100	Y	Y	1	
189	72418.4	724.2	2	2	20	100	100%	100	Y	Y	5	
190	1050.7	1050.7	1	2	20	1	100%	80	Y	Y	1	
191	1079.6	269.9	1	2	20	4	100%	80	Y	Y	1	
192	1130.3	113.0	1	2	20	10	100%	80	Y	Y	1	
193	1207.6	60.4	1	2	20	20	100%	80	Y	Y	1	
194	2049.2	20.5	1	2	20	100	100%	80	Y	Y	5	
195	1050.7	1050.7	1	2	20	1	100%	100	Y	Y	1	
196	1085.1	271.3	1	2	20	4	100%	100	Y	Y	1	
197	1153.9	115.4	1	2	20	10	100%	100	Y	Y	1	
198	1268.7	63.4	1	2	20	20	100%	100	Y	Y	1	
199	2481.8	24.8	1	2	20	100	100%	100	Y	Y	5	
200	12589.1	12589.1	2	2	2	1	100%	100	Y	Y	1	
201	14483.0	3620.8	2	2	2	4	100%	100	Y	Y	2	
202	19203.8	1920.4	2	2	2	10	100%	100	Y	Y	5	

Table B-1

Listing of Computer Outputs (Cont.)

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Summary Run Number	Program Cost, K$	Element Unit Cost, K$	Element Number	Line Number	Production Rate Capability/Year	Quantity Produced	Depreciation Method	Learning Curve, %	Property Tax, $30/1000	Interest on Capital, 6%	Program Length-Years - Basis for Taxes, Interest and Depreciation as Appropriate	NOTES
203	1077.9	1077.9	1	2	2	1	100%	100	Y	Y	1	
204	1207.6	301.9	1	2	2	4	100%	100	Y	Y	2	
205	1542.5	154.3	1	2	2	10	100%	100	Y	Y	5	

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